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American Concrete Institute

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JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

News AMERICAN CONCRETE INSTITUTE Letter

THE NEW JOURNAL is to give frequency, timeliness and additional capacity to the Institute's forum.

The annual three-day meetings have provided invaluable personal contacts and technical sessions too crowded with subject matter for adequate discussion of much that was brought to them. Annual publication of *Proceedings* resulted in so large an array of papers and reports at one time as to dampen the ardor of all but the more tireless of readers in a field of interest as eager as that which the Institute aims to serve.

The JOURNAL, available ten times a year, takes the excess burden off the annual convention, increasing the membership asset of personal contacts. With fewer subjects on the program, their value is enhanced through opportunity for more detailed consideration.

The JOURNAL will report what the convention program produces; it will encourage that pre-convention consideration which formerly necessitated separate preprints; it will extend the periods for discussion; it will afford a place for the timely issue of many papers and reports which crowded programs formerly discouraged.

These NEWS LETTER pages will continue to serve as originally intended—to keep members in touch with organization activity. They will record also fragments of fact and opinion which issue from laboratory, field, shop and office—sometimes stimulating, provocative—which, because fragmentary, fall just short of development in formal papers. Such material, perhaps in a single challenging paragraph, may serve to spur research or inspire better practice, in a field whose evidences of progress are not all immediately available in formal contributions. Many will contribute such fragments (every now and then they brighten the incoming mail) while only a few will digest, analyze, correlate, to produce papers of that more studied character which you will expect to find in the *Proceedings* pages of this JOURNAL.

And then, a little later, there will be added a section of Abstracts of the current literature of concrete.

A CONCRETE CONGRESS IN 1933, PROPOSED

A SPECIAL Institute committee has been named to report to the Board of Direction in February next on a proposal of the Advisory Committee, A. R. Lord, Chairman, to recognize the scientific character of the Chicago World Fair in 1933 by the organization of a Concrete Congress which would replace the Institute convention of that year.

Preliminary suggestions to that end, discussed by the Board at its meeting October 5, included:

Scope: The entire field of concrete, materials, properties, design, construction, special uses.

Participants: Invite cooperation of leading technical societies having an interest in the subject matter.

Committees: Concentrating on special assignments to produce concise statements of significant facts and of their relation to practice; their preliminary reports to be published in 1931 as a basis of supplementary effort to close important gaps in existing knowledge and revised and republished as agenda for the Congress.

Exhibition: In its housing and its detail to set forth the best knowledge of the material, its constituents, fabrication and application.

Afterward: The final product of the Congress to be compiled in two volumes (1) A digest of significant facts pertaining to concrete; (2) A manual of practice.

This would bring to bear a more comprehensive effort on a program for digest and manual set up by the Institute a year ago as the definite objective of the next few years.

To consider these proposals, their feasibility and ways and means to make them effective, the Board authorized a special committee of nine which President Boyer has appointed as follows: A. R. Lord, Chairman; Duff A. Abrams, Cloyd M. Chapman, A. E. Lindau, Arthur N. Talbot, H. C. Turner, George E. Warren, R. B. Young, Harvey Whipple, Secretary.

* * *

THE 1931 CONVENTION—WHERE?

EACH year the Institute is in receipt of more and more invitations from municipalities, their chambers of commerce and publicity bureaus (not to mention members with home town hospitality) who wish to entertain the Institute on the occasion of its next convention. All of which is very pleasant—the Institute has grown—its annual meeting is worth while and not without local significance wherever it may be.

Also, the problem of selecting the next convention city becomes more complicated.

It has seemed best to the Board of Direction of the Institute to adopt at least a policy in outline. This policy arises in the present state of our membership distribution, from a belief that the Institute should *in general*, alternate between East and Middle West, with an occasional departure, (every three or four years) from the denser membership areas (as in 1930, to New Orleans). The Secretary has therefore been asked to take an advisory ballot of the membership to help the Board of Direction decide among the following six cities for the 1931 meeting: Chicago, Indianapolis, Kansas City, Louisville, Milwaukee, St. Louis. Blank ballots will be sent to all members sometime before the February 1930 meeting.

A COMPREHENSIVE INVESTIGATION OF REINFORCED CONCRETE COLUMNS

A STATEMENT BY COMMITTEE 105,—REINFORCED CONCRETE COLUMN INVESTIGATION

RECENT efforts to standardize building codes have disclosed a wide variation in the method of designing reinforced concrete columns. These differences are not alone in the matter of the form which the various formulas take, but in the resulting permissible loads on a given column. A column designed to carry a given load in one city would be very much too large under the provisions in effect in another city.

Obviously the columns designed under the various codes cannot all be economical. Either some are stressed above the intended limits or the others are wastefully designed. Such a condition can be remedied only by a thorough investigation of the reinforced concrete column in which all of the factors bearing on the problem are fully studied, so that the distribution of the load between the reinforcement and the concrete may be determined with some exactness. With this distribution determined, it will be possible to design columns to take into account difference in relative cost of the concrete and steel in different localities, and thus provide for economical use of the materials consistent with the prescribed limiting stresses.

Such an investigation at this time is also desirable in view of the trend toward high strength concretes. In none of the early column tests were many columns of high strength included. As a result, the provisions for these types have been very conservatively drawn. Much more liberal provisions may be expected from an investigation based on present day conditions.

An opportunity is now presented for an investigation of reinforced concrete columns which will clear up the points of difference, and extend the knowledge of column behavior to the high strength concretes now rapidly coming into use. The support of every organization interested in reinforced concrete construction is needed to make this investigation adequate to the possibilities it holds forth.

This investigation is being sponsored by the American Concrete Institute through its Committee 105 on Reinforced Concrete Column Investigation. The general scope of the study is to establish the fundamental relationships between the load, elastic properties, and ultimate strength of reinforced concrete columns as affected by variations in size, quality of concrete, amount and arrangement of reinforcement, rate and method of loading, and the effect of continuous load over long periods of time.

The investigation as planned, is the most comprehensive ever undertaken, and if adequate support is forthcoming it may be expected to extend materially the application of reinforced concrete columns. Nearly fifteen years have elapsed since the results of an extensive series of column tests have been published in this country. The great improvements which have been made in that time in the control of strength of concrete should aid greatly in securing uniformity of results and thus make more certain the conclusions to be arrived at. In view of these facts the study should definitely result in a rational method of design which will permit the most economical use of concrete and steel to meet any load requirements for a given cost basis.

It is anticipated that the results of these studies will permit a wider use of high strength concrete in column construction making possible a considerable reduction in size from the present prevailing practice. This should not only increase the attractiveness of reinforced concrete for tall building construction, but also permit a big reduction in the number of stories in which steel cores are required in such buildings.

* * *

THE COLUMN TEST FUND

ABOUT $13,000 has been pledged toward a possible need of double that amount to carry on the comprehensive series of tests of reinforced concrete columns under the direction of American Concrete Institute Committee 105, Reinforced Concrete Column Investigation. (A statement from the committee appears elsewhere in these pages). The work is in the new Institute Department of Research, F. R. McMillan, Chairman.

The tests will be undertaken in two engineering laboratories. Cooperative agreements with the University of Illinois for the Engineering Experiment Station of the university and with Lehigh University for the Fritz Engineering Laboratory are in preparation. Committee 105, in charge, is as follows: W. A. Slater, chairman; R. L. Bertin, F. E. Richart, W. S. Thomson, R. D. Snodgrass.

As soon as the Institute Board authorized the undertaking, preliminary effort at financing was started. The Portland Cement Association contributes $6,000 in the services of two men, one to work under the direction of Professor Slater at Lehigh, one under Professor Richart at Illinois. The Concrete Reinforcing Steel Institute and the Rail Steel Bar Association, pledged $2500 each.

At the request of the Board of Direction, Henry C. Turner, President, Turner Construction Co. then took charge of the fund-raising among material producers, engineers, contractors and others who have a very definite and practical interest in the information to be gathered. He has undertaken, with the cooperation of interested members of the Institute in a score of larger centers, to raise the additional money needed to insure success of the important undertaking.

In New York City at a luncheon meeting with twenty-six in attendance, $2200 was promptly pledged by about half those present, with about $1800 more anticipated from members of the New York group who are expected to sign pledges within the next few days.

John G. Ahlers of Barney-Ahlers Construction Corp. is chairman of the New York group. A. C. Tozzer of the Turner Construction Co. represented Mr. Turner (absent because ill). They, with President Boyer, outlined the practical significance of the undertaking and visioned this as a new start to grapple major research problems under the auspices of the Institute, in assuming a responsibility which belongs to all the working units of the entire field, rather than to any one part of it. Two $400 pledges were made, two of $250 each, and several of$200 and $100 each.

The Institute acknowledges receipt up to November 15 of the contributions listed below. These amounts have been deposited to the credit of a special Reinforced Concrete Column Test Fund.

	Actually received
Concrete Reinforcing Steel Institute, Chicago	$2,000.00
Rail Steel Bar Association, Chicago	2,000.00
N. Y. Trap Rock Corp., New York	100.00
Industrial Engineering Co., New York	100.00
Henry Steers, Inc., New York	100.00
White Construction Co., New York	200.00
Wm. J. McCormack Sand Co., New York	100.00
The Foundation Co., New York	100.00
MacArthur Concrete Pile Corp., New York	100.00
	$4,800.00

FEND PLANT DISEASE WITH CONCRETE

FROM A LETTER

IN TEXAS we have a very serious plant disease known as root rot which attacks cotton and a large number of other crops. This disease destroys shrubs and trees as well. In our research we find that we can control the disease by sifting the soil and removing infected roots. This, however, can be effective if the sifting is done quite deeply, probably from three to five feet. While this method may not have a practical application under field conditions, we believe that it has a direct application when it comes to protecting flowers, shrubs, and trees in city lots where the root rot disease is a serious problem. I believe that we could probably grow trees in root rot areas if we can dig out a deep hole, take out the soil, sift it and replace it, and have this sifted soil protected by a solid wall of some kind. I have in mind the construction of underground miniature silos which could be filled with sifted soil and shrubs and trees planted. Such a silo construction will, of course, have to have a bottom. I am of the opinion that perhaps concrete structures of that kind will answer the purpose.

J. J. TAUBENHAUS.
Texas Agricultural Experiment Station

THE HONOR ROLL

IN OCTOBER, W. F. Way, Seattle, added one more to the new members approved on his sponsorship. He therefore ties H. F. Gonnerman, Chicago, for first place on the 1930 Honor Roll which is open until February 1, 1930. Mr. Gonnerman and Mr. Way have nine members each to their credit since February 1, 1929.

I. E. Burks is next with 7; H. B. Emerson, Chicago and George E. Fenkell, Detroit tie in third place with 6 each. M. M. Upson, New York, (absent now in Japan) is fourth with 5; E. Y. Bragger and F. R. McMillan have 4 each. D. A. Abrams, John G. Ahlers, W. D. M. Allan, L. E. Andrews, H. J. Gilkey and Miguel Villa (Cuba) have three each.

Following are listed 12 members who have two new members each to their credit—*almost* on the Honor Roll.

F. C. Brookhouse	2
J. Campbell & Sons, Ltd.	2
B. E. Clark	2
A. K. Dandekar	2
G. J. Eyrick	2
J. C. Hawkins	2
A. R. Lord	2
W. S. Loucheim	2
B. A. Rich	2
F. E. Richart	2
C. J. Seibert	2
John Tucker, Jr.	2

Besides there are 76 members on the office list, each of whom has sponsored one new member since Feb. 1, last.

10,000 Lb. Concrete

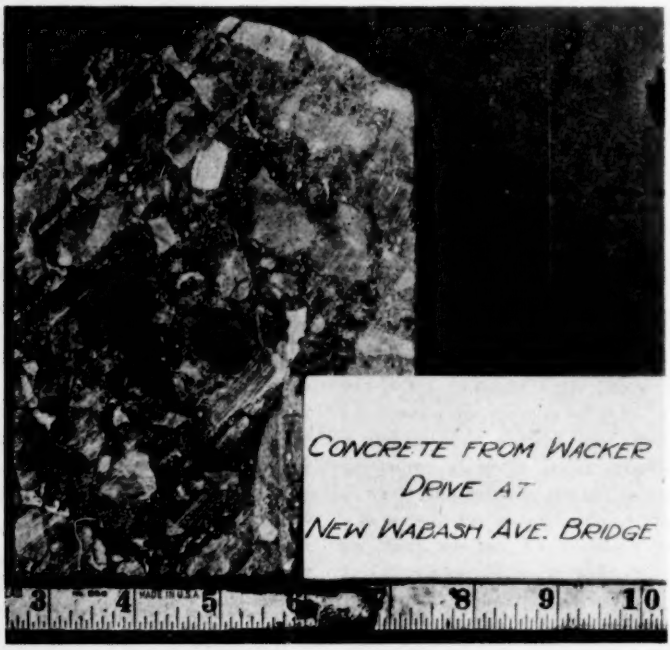
In 1927, the high standards successfully maintained on the construction of Wacker Drive, a two-level river-front boulevard of reinforced concrete, in Chicago, were described in a paper* before the American Concrete Institute by Arthur R. Lord, consulting engineer on the work. The construction of the abutments for a new bridge across the river at Wabash avenue has involved the removal of a large area of the Wacker Drive superstructure. Samples of concrete were taken at random from the debris of the cutting and five tests were made of the superstructure concrete and one test of the paving base concrete. These samples were sawn to three-inch cubes and were approximately forty-six months old when tested. The results are tabulated:

*Awarded the Wason Medal, 1928.

Sample From	Test No.	Crushing Strength—Lb. per Sq. In.	
		3 x 3-in. Cubes	Equiv. Cylinder*
Superstructure	1	10,200	8,700*
	2	11,800	10,100*
	3	12,700	10,800*
	4	11,200	9,500*
	5	11,200	9,500*
	Average	11,400	9,700*
Paving Base	6	10,200	8,700*

*The cylinder strength equivalent to the actual cube strength has been taken as eighty-five per cent.

The record shows that this concrete was placed January 6 and 7, 1926, near the end of a continuous concreting operation begun January 4 and continued,



A Section of Wacker Drive Concrete of the Kind Reported in Recent Tests

day and night, for 98 hours. At the Wabash avenue area the work was overtaken by a cold period, with minimum temperature reaching 0° F., followed by a snow storm. Water, sand and stone were heated and the concrete delivered to the forms at a temperature of about 60° F. The upper surface of the slab cooled to about 35 to 40° F. before it was covered. A temperature of from 55° F. to 85° F. was maintained in the enclosure under the forms for one week and the upper surface of the slab was covered with hay as soon at it was hard enough to walk upon. The mix was 7 sacks of cement to 14 cu. ft. of sand to 22 cu. ft. of crushed stone; water-cement ratio approximately 6.5 gallons of water per sack of cement. Eighteen sets of test cylinders made January 6 and 7, gave an average crushing strength of 2120 lb. per sq. in. at seven days and of 2620 lb. per sq. in. at 28 days. The average slump for the two days was 2.9 inches. Thus the 46-month tests show a strength over three times that at 28 days. This may be misleading, since the curing temperatures during the last three weeks of the 28-day period averaged only 25° F. By Slater's equation, $S_{28} = S_7 + 30\sqrt{S_7}$, the 28-day strength of this concrete should have been about 3500 lb. per sq. in. under favorable curing temperatures. The 46-month strength is two and one-half times the 28-day strength, even on this basis.

The concrete samples all showed small air pockets (see the picture) distributed through the mass, indicating that the concrete was slightly too stiff for complete consolidation by ordinary placing methods. On Wacker Drive the upper surface of the concrete is protected by membrane waterproofing. For structures without such protection probably a slightly greater slump should be permitted (with a decrease in the strength of a 1:5 mix) or the fresh concrete should be vibrated to insure a watertight slab.

* * *

CINDERS

FROM A LETTER

AMONG the many excellent new committees of the Institute one should be established to consider *Cinder Aggregate and Cinder Concrete*. So far as I know there exists no standard for safeguarding the quality of cinders used in structural cinder concrete slabs. Such floor and roof slabs are in common use especially in Eastern cities. The cinders for such concrete may come from yesterday's boiler firing or from some dump where they have lain for years, acquiring an "admixture" of tin cans, dead cats or what-have-you. The cinder pile itself is all too commonly a dump for other daily refuse. I understand that on a *single day* last summer in New York the cinder concrete placed on *five* scattered large structures failed to harden. Investigation finally disclosed that a small amount of sugar had been introduced into the cinders in some unknown manner. These floors, too weak to stand up under their own weight, need cause us no concern, but what about other floors whose cinder concrete is *just barely* able to support itself in place? It would seem that the Institute may perform a service by setting up safe standards for cinders and for cinder concrete for structural use, in view of the economic value and very large use of this type of construction.

In the case of cinder blocks, I am not informed as to the quality of cinders used. But I am informed that an ordinance recently passed by the

Chicago City Council permitting the use of cinder block in that city, sets up no safeguards whatever on the quality of cinders to be used.* Doubtless every janitor sees new value in the fluffy ashes that he has been throwing away. Even a new "racket" may develop in this material of newly acquired dignity! While reliable manufacturers of cinder blocks will continue to take all necessary precautions in their own plants it would appear that they should welcome the assistance of the Institute in defining "good character" in cinders and in making possible the continued satisfactory development without setbacks, of this excellent, light weight and inexpensive building material.

There is still a third field for this committee (if any *one* committee can straddle so many of your new departmental lines) and that is to investigate the structural action of and set up proper standards for design of cinder concrete slabs. Do such floors act as continuous slabs, as arches or as suspension members? Is the cinder concrete purely a filler or is it under stress? How much strength does it need to have? How much deflection and how much cracking should be expected and allowed? Is the action of cinder concrete any different from the action of stone concrete in these matters and is there good reason for running the steel stress up to 30,000 pounds per sq. in. or so as appears to be permitted in the New York practice in some instances? I understand fully that the Institute does not finance tests and that some of the questions can hardly be answered in any convincing manner without rather extensive tests, but is it not possible that those interested in cinders, cinder block or welded wire reinforcement may be willing to finance such tests as are found to be essential by this committee for its study?

I can think of a few more questions to engage the attention of such a committee! Will good cinders act chemically on the reinforcement, either in a dry floor or in one where water is present? Just how much cement is necessary to transform a cinder *fill* into cinder concrete? How much strength is necessary to prevent the cement mortar coat from curling up the cinder concrete filling on which it is placed? What is the water-cement-strength relation for cinder concrete? Does the original Abrams' formula, $S = \frac{14000}{7^x}$, apply for such loose porous concrete? Possibly someone (or some several) knows the answers to all these inquiries, and no task remains for such a committee. In view of his personal dense ignorance, the writer would prefer that you use unsigned copies of this letter, should you set out to find the answers to these questions among your membership.*

* * *

OLD CODES

ANALYSIS of replies to a questionnaire from the Division of Building and Housing, Bureau of Standards, to officials of cities of 5000 and up, discloses 858 cities, towns, and villages of whose building codes, 67 are 20 or more years old, 85 are 15 or more years old, and 159 whose codes are 10 or more years old. Some of them have subsequent amendments tending to make them more up-to-date.

*Perhaps the code does set up a standard for the block made from them.—EDITOR.

*Anonymous letters should not, usually, be dignified by public print. This seems to be an exception to the rule since there is no question of good faith, especially as the letter is anonymous only as published.—EDITOR

CINDER CONCRETE AND HEAT TRANSMISSION

WALTER W. WELSCH, Welsch Waterproof Block Co., Joliet, Ill., expressed concern about what he regards as an upset of prevalent belief which he found in Institute *Proceedings*, Vol. 25—"Characteristics of Concrete for Fire Resistance," the report of Committee E-4, p. 812. Mr. Welsch calls attention to paragraph 4, p. 814:

Contrary to a quite general impression cinder concrete, of all the concretes, is relatively poor for insulating against fire. It transmits heat somewhat more readily than the siliceous gravel concretes and while it does not spall it usually suffers great loss of strength. Because of the high rate of heat transmission the thickness of protective coverings should be greater than for most of the other concretes. Cinder concrete in actual service, so far as the records disclose, has not been unsatisfactory. This is probably due to its use only in relatively minor members of structures and as fireproofing for structural steel. Clean hard burned clinkers as aggregates give much more favorable results than cinders. The heat transmission is less and the residual strength proportionately much greater. Coke breeze as an aggregate has been found in tests to make concrete of good heat insulating properties but is not satisfactory for reinforced concrete subjected to severe fires.

Nolan D. Mitchell, structural engineer, National Bureau of Standards and chairman of the committee which prepared the report, was consulted. He cites references in the report as follows:

"Fire Resistance of Different Concretes," *Engineering Record* Volume 2, p. 97, July 1905. "Investigation of the Thermal Conductivity of Concrete and Effect of Heat on Its Strength and Elastic Properties," Ira H. Woolson, Proceedings of American Society for Testing Materials, Volume VI, p. 433 (1906); Volume VII, pp. 404-418 (1907). Also *Engineering News*, June 28, 1906; and August 15, 1907.

"Heat Insulating Properties of Some Materials Used in Fire Resistive Construction," Technologic Paper No. 130, National Bureau of Standards (1919). British Fire Prevention Committee Red Books No. 251 and 252, "Conductivity of Heat through Concrete Slabs."

Further he expresses the belief that "since the paper discusses reinforced concrete and concrete as fireproofing, the evidence justifies the conclusions drawn with reference to cinder concrete. The tests of the Bureau of Standards, the British Fire Prevention Committee, Professor Woolson's tests of various concretes, and the Chicago column tests at the Underwriters' Laboratories all indicate the relatively high rate of heat transmission through cinder concrete. Mr. W. A. Hull in his paper before the A. S. T. M. Proceedings Vol. XVII, pp. 424—442, discusses heat transmission through concrete. On page 442 he states that 'cinder concretes from bituminous coal cinders are apparently to be viewed with suspicion, especially if the cinders contain much combustible material, which is apt to be the case with cinders from bituminous coal.' On page 438, Vol. VI (1906) Proceedings A. S. T. M., Professor Woolson states, 'It is rather surprising to note that cinder came next to gravel in the amount of interior heat recorded for cinder concrete is well known to be an effective fire resistant.' See, also, pp. 406, 407, and 408, Vol. VII (1907) Proceedings A. S. T. M., which verifies the previous tests relative to cinder and other concretes.

"The following is quoted from the last reference: 'The fact that cinder concrete showed a higher thermal conductivity than the stone concrete would indicate that its well known fire-resistive qualities are due, in part at least, to the incombustible quality of the cinder itself.'

"Nearly all comparative tests have shown that cinder concrete at high temperatures will transmit heat more rapidly than other kinds of concrete. This is not the case, however, *for ordinary climatic temperatures.* This difference is probably the cause of the erroneous impression concerning the heat conductivity of cinder concrete as a fireproofing material.

"It is believed that the preponderance of the evidence supports the conclusions given in the Report of Committee C-4, which deals principally with reinforced concrete.

"Perhaps the picture will not look so gloomy to Mr. Welsch if he will read the first sentence of the report and the entire paragraph from which he has quoted, taking into consideration the fact that compared with most other types of building constructions well made reinforced concrete buildings even with cinder concrete have a very high degree of fire resistance."

Mr. Mitchell further explains that the high temperatures to which he referred would be those from 1200° F. up. "These temperatures are reached in dwelling house fires if no water is applied. They would usually be of short duration under such circumstances."

* * *

An Extension Course in Concrete

It has been proposed to the Board of Direction that the Institute sponsor a course in concrete and concrete construction to be used in extension work of one of the country's largest universities.

Securing Steel and Steel Forms

John M. Bischoff, Commissioner Detroit's Department of Buildings and Safety Engineering, says in a recent bulletin:

Reinforcing Members—The inspectors of this department have recently reported a large number of serious violations of Article XIII, Section 17, of the Building Code. This section required that "all reinforcing members shall be accurately located in forms and secured firmly against displacement." Instead of this it has been frequently observed that bars are thrown in loosely and "hooked" up after the concrete is poured, with the result that very little of the steel is correctly located in the finished work. Concrete work conducted in this way, will be from 30 to 50 per cent weaker than calculated and in some cases is positively unsafe for the intended use. This department does not consider the use of chairs, spacer bars, etc., and the wiring in place of reinforcement to be an unnecessary or undue expense, but on the other hand considers such device necessary for the accomplishment of good and safe work. It is our opinion that these devices should be specified as included in the reinforcing steel.

This department will, in the future, decline to approve plans and specifications for reinforced concrete construction in which some positive method of fixing and supporting the steel forms is not specified and our inspectors will be instructed to take immediate steps to stop the progress of all concrete work upon which these forms are not properly supported and fixed in place before the concreting is started.

The steel forms of the permanent or removable type must be made from material of not less than No. 26 gauge and must be reinforced by ribs in two directions or other approved methods so as to withstand without distortion, the usual construction loads while concrete is placed.

The steel tile shall be secured to the wood forms by nails, staples or some

positive metal clamp, at intervals not exceeding six inches on both sides, to maintain the required joist width as called for in the design of the reinforced concrete.

* * *

CEMENT REFERENCE LABORATORY

The Cement Reference Laboratory, recently established at the Bureau of Standards, under a sponsorship of Committee C-1 on Cement of the American Society for Testing Materials has begun the inspection of cement testing laboratories as part of the program to secure improvement in the testing of cement. The inspectors are now in the field, caring for some of the requests already received. There is no fee for the work done in the field. However, the inspectors will visit only those laboratories which request their services and it may not be possible for them to visit some localities very frequently. Therefore, those laboratories which desire but have not already requested inspection, should promptly address the Cement Reference Laboratory, Bureau of Standards, Washington, D. C., in order that advantageous schedules may be arranged for the inspectors.

* * *

NEW BROOMS AND VIEWPOINTS

IT HAS been seriously suggested by a thoughtful member that technical society program committees should adopt a rule to disqualify a man from participation in a symposium, who has previously written on its subject. He points out that we need fresh viewpoints and can well afford to risk error for a possible new idea—for new approaches to the solution of many of our problems. Anyway, *this* seems to be a new thought.

DISCUSSION

Discussion of papers and reports published this month should be available before February 1 with a view to their publication in the JOURNAL for March 1930. It is recommended that prospective contributors to discussion make their work available early. Late discussion or the later contributions to discussion which may be too voluminous for inclusion in a single issue, will be carried over possibly for several months.

* * *

PLACING CONCRETE IN FLAT SLAB COLUMNS

SAUL UHR, Philadelphia member, finds disagreement as to best practice "in pouring flat slab columns—whether to the bottom of the capital or to the bottom of the drop." His inquiry discloses prevalent practice is to pour to the bottom of the drop, "contrary to the requirements of Section 507f, of the Institute's 1928 Tentative Building Regulations for Reinforced Concrete," because when poured to the bottom of the drop, "it is easier to clean the top of the column." He wants to know if prevalent practice is full of hazard or the regulations of error.

* * *

ENGINEERS VS. STANDARDS

FROM A LETTER

THERE is much need for a better understanding of the function of the engineer in the scheme of the present day order of things. The tendency to standardization is not redounding to his credit and neither is it an earnest of his intelligence. Some day he will wake up and realize that by this fetish he is merely submerging himself and hiding his talents behind a barrier of

mediocrity. The unfortunate thing is that, while the engineer by his own acts thus conceals his capacity, his soul continually yearns for recognition and his mind wonders why it is denied him.

THADDEUS MERRIMAN.

* * *

NEW MEMBERS

Applicants for membership in October, 1929, approved by the Board of Direction are:

Campbell, J. Bow, Box 39, Bethlehem, O. F. S., South Africa.

Empire Stone Company, Ltd., Thanet House, 231, Strand, London, W. C. 2, England.

Giguel, R. Sanchez, Calle 27, No. 23, Vedado, Havana, Cuba.

Hannas, Oliver J., Y. M. C. A., Green Bay, Wis.

Hudson Block & Supply Co., Inc., 5274 Hudson Blvd., North Bergen, N. J. (W. J. Dicker, Gen. Mgr.)

Kennoy, John S., Box 459, Hot Springs, Ark.

Los Angeles Public Library, 530 So. Hope St., Los Angeles, Calif. (Albert C. Read.)

Mason, Roscoe J., 3221 Lenox Ave., Detroit, Mich.

Moran, Robert L., 9 Wellington St. W., Toronto 2, Ont., Canada.

Reis, F. Santos, Barao Bom Retiro, 58, Rio de Janeiro, Brazil.

Richard, N. A., Vice-Pres., Purdy & Henderson Company, 45 East 17th St., New York, N. Y.

Sampson, B., Birchard Construction Co., 1129 J. St., Lincoln, Nebr.

The Sisalkraft Co., 205 West Wacker Drive, Chicago, Ill. (E. T. Anderson, Pres.)

Smallwood, H. S., 410 No. "D" St., Tacoma, Wash.

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*For formal presentation and discussion at the 26th Annual Convention, New Orleans, Feb. 11-13, 1930. Written discussion will have prior consideration on the program and for publication.

Discussion of the contributions in the following 100 pages is scheduled for publication in the JOURNAL *for March 1930 and should be available not later than Feb. 1.*

Construction Specification For Concrete Work On Ordinary Buildings

Proposed American Concrete Institute Specification No. 502
(To be Used on Buildings Requiring Considerable Concrete)

BY ARTHUR R. LORD,* AUTHOR-CHAIRMAN
Committee 502—Mixing and Placing Concrete on Buildings

Editor's Foreword

THIS *is the first of a contemplated new series of specifications to be prepared and issued under the auspices of the American Concrete Institute. Others are in progress, including Specification No. 503 for Fabricating and Setting Reinforcing Steel, a companion document to the one here presented. It is hoped—expected that Institute members will be served not merely in their use but in that discussion by which they may be perfected for use.* * * * *The new committee plan of the Institute, in which a single member prepares the report and others of experience criticise it in advance of publication, has been applied to the production of the specification which comprises the report of Committee 502, whose work is in the new Department of Specifications.*

The Author of Proposed Specification No. 502 is exceptionally qualified for this work. He brings to it a diverse experience with concrete—research under Professor Talbot at Illinois; chief engineer of one of the larger construction companies for many years and independent practice as an architectural engineer in the special field covered by this specification for the last fifteen years, in which many notable structures have been designed and constructed under his supervision—and many smaller ones as well. He is the author

*President, Lord and Holinger, Inc., civil and architectural engineers, Chicago.

of "Design and Cost Data for the 1928 Joint Standard Building Code," a notable 1928 paper before the Institute (Vol. 24, p. 537) which with Building Regulations for Reinforced Concrete, tentatively adopted by the Institute the same year, comprise the "Handbook of Reinforced Concrete Building Design," and of many other published bulletins, books and articles on concrete, including his 1927 Institute paper: "Notes on Concrete—Wacker Drive, Chicago" which made him a Wason Medalist for that year.

Critic members of the committee, A. S. Douglass, A. B. MacMillan, J. Thumley, W. F. Way brought to their task a varied and thoroughgoing experience in the work covered by such a specification.

The specification has the approval in general of all four critics and in detail with exceptions noted in discussion by Messrs. Douglass and MacMillan, following the report in these pages.

And for all the labor which goes to make such a document, and for all the well considered experience from which it is drawn—no specification is final except as made an effective part of each building contract. A composite of the accretions of experience, it will continue to grow from the experience of others yet to be heard. Thus, the Institute's work is effective as such a specification draws upon the experience of all. Even when and if acceptable and adopted as an Institute standard, it becomes but a temporary "last word"—a new point of departure for still better practice than it implies. To attribute to standards any undue degree of finality is an obstacle to the purpose of the Institute. No small part of the good of a specification is in the rub of comparative judgment and experience through which it is adopted. It is with this thought that the Program Committee has placed the report of Committee 502 on the 1930 convention program and invites discussion.—EDITOR.

TO THE USER

THIS specification is intended for the use of Architects and Engineers, to be incorporated as a whole in the specifications for particular structures by reference at the proper place in the typewritten pages and to become a part of the contract in the usual manner. It applies to ordinary commercial or industrial buildings or to other buildings in which ordinary concrete surfaces, as they are produced by reasonably good formwork and concrete control are acceptable. For fine architectural surfaces it should not be used. This specification also incorporates (unless stricken out by the user) Specification No. 503* for Fabricating and Setting Reinforcing Steel in this type of building.

In the preparation of this specification, the author has had the active criticism and cooperation of the critic members of the committee: A. S. Douglass, construction engineer, Detroit Edison Co.; A. B. MacMillan, chief engineer, Aberthaw Co., Boston; J. Thumley, superintendent, Graham, Anderson, Probst & White, architects and engineers, Chicago, and W. F. Way, Henry & McFee Contracting Co., contractors and engineers, Seattle.

The following wording is suggested to be used in the Architect's and Engineer's typewritten specification for individual building:

Specification for Concrete Work
Name and Location of the Building
Name and Address of Owner
Name and Address of Architect or Engineer

All plain and reinforced concrete work on this structure shall be done in strict accordance with Specifications Nos. 502 and 503 of the American Concrete Institute, which are hereby made a part of these specifications and which will be made a part of the contract for this work. All the provisions of these two specifications shall be in full force and effect except as expressly modified or supplemented in the following special instructions for this structure.

(Here incorporate any necessary clauses arising from unusual conditions surrounding the work to be done, as for example: quicksand or unusual water conditions; protection of existing construction; materials purchased or furnished by the Owner direct; early strength concrete; unusual chemical exposures to be safeguarded; maintenance of manufacturing operations during construction; concrete piles, caissons or tunnels; very deep basements; underpinning work; special grading or maximum size of aggregates with revised fineness modulus; admixtures; etc.; etc.)

*In Preparation by Committee 503—Fabricating and Setting Reinforcing Steel. William F. Zabriskie, Author-Chairman.

Wherever the words "Architect or Engineer" are used they shall be construed to mean the Architect Engineer (Strike out one) only or his duly accredited representative on the work.

1. GENERAL CONDITIONS OF THE CONTRACT

This Contractor shall acquaint himself fully with the General Conditions of the Contract for this work. He shall be bound by all requirements of these general conditions insofar as they are applicable to his part of the work in the opinion of the Architect or Engineer. These General Conditions shall be made a part of the contract for the concrete work covered by this specification.

2. SCOPE OF THE CONCRETE WORK.

This Contractor shall provide all necessary labor and material and install complete, ready for convenient use, all portions of the structure specifically mentioned in these specifications and/or shown on the architectural or engineering plans or details of the structure, and also all usual necessary and essential portions of a structure of this type that would commonly be made of plain or reinforced concrete, whether or not they are definitely shown on the plans or listed in the specifications. In general the work of this Contractor shall include: concrete foundations; concrete floors on the ground, including fine grading and filling therefor; concrete retaining walls at building lines and area ways; concrete columns, roofs and floors; concrete walls; concrete or terrazzo floor or stair finish; any cutting, shoring, sheeting, hand excavation, backfilling or underpinning necessary to install concrete work properly; concrete sidewalks, paving and parking strips; installation of masonry ties or other inserts; concrete stairways; concrete penthouses or tank supports; formwork for all concrete work requiring same; and so forth. This contractor shall also furnish and place all necessary reinforcing material, properly bent and marked, together with complete accessories to hold securely all reinforcement in its designed position during construction.

3. CONDITIONS AT SITE OF WORK.

This Contractor shall visit the site of the work and make himself thoroughly familiar with all conditions affecting the conduct of his work, the location and arrangement of his plant, the storage of materials, and so forth. He shall make any necessary observa-

tions as to soil conditions, ground water level, sewers or public utilities, traffic requirements and so forth. No additional allowance of time or money shall be asked or granted because of this Contractor's lack of knowledge of conditions prevailing at the site at the time of estimating or which may be readily foreseen to exist at the time that the work is undertaken.

4. PRELIMINARY PREPARATIONS.

Promptly upon the receipt of contract for this work this Contractor shall decide upon the materials to be used in the work, furnish adequate samples of them to the Architect or Engineer and shall cause to be made such tests as are herein specified (Articles 17 and 18) for the determination of the mix. He shall also make all necessary arrangements for tools and equipment and for the installation of his mixing plant and conveying equipment, except as he may arrange to secure his concrete from a central mixing plant approved by the Architect or Engineer. No hand mixed concrete shall be used on account of the failure of this Contractor to make adequate preparations, but concrete needed before the job plant is ready, at times when it is disabled or after it has been dismantled, shall be procured from an approved central mixing plant.

5. CEMENT.

Portland cement, meeting all requirements of the standard specifications of the American Society for Testing Materials (serial designation: C9-26) shall be used for all concrete work.

Cement shall be delivered in cloth or paper sacks plainly marked with the name of the manufacturer and shall be stored for at least seven days in sealed warehouse after test samples are taken. It shall be so stored and handled at all times as to be protected from moisture from the air or from the ground or from any other source. It shall be so stored as to be readily inspected and as to remain free of any foreign material. All the cement in any container, in which part of the cement has become caked or has otherwise deteriorated, shall be entirely removed from the work.

6. FINE AGGREGATE.

Fine aggregate for this work shall consist of well graded natural or artificial sand taken from sources that have furnished satisfac-

tory material for previous concrete work for several years, or if from a new source, shall be thoroughly tested for soundness and permanence. It shall have a fineness modulus of not less than 2.75. It shall not contain in excess of two per cent (by weight) of dust passing the 100 sieve when thoroughly dried. It shall be free from organic matter and dirt and shall be so stored and handled at all times as to remain free of all foreign material and separate from other aggregates until placed in the mixer.

7. COARSE AGGREGATE.

Coarse aggregate for this work shall consist of washed gravel, crushed rock, or similar inert materials, taken from sources that have furnished satisfactory material for previous concrete work for several years, or if from a new source shall be thoroughly tested for soundness and permanence. It shall have a fineness modulus not less than 5.5. It shall be well graded from fine to coarse and not more than five per cent (by weight) of the particles shall be retained on the one-inch sieve.* It shall be free from organic matter and dirt. It shall not contain in excess of two per cent (by weight) of dust passing the 100 sieve, nor in excess of three per cent (by weight) of soft, friable, thin, flaky, elongated or laminated particles.

Coarse aggregate shall be so stored and handled as to remain clean and well graded at all times and shall be kept separate from other aggregate until placed in the mixer.

8. WATER.

Water used in the concrete for this work shall be taken from a source which has proven satisfactory on similar work. Surface water shall not be used nor water subject to pollution by industrial waste, except after tests satisfactory to the Architect or Engineer. Where city water is used the same shall be paid for by this Contractor. (See also article 25 of this specification).

9. CONSTANT SOURCE OF SUPPLY.

Having determined upon the source and kind of cement and aggregates to the satisfaction of the Architect or Engineer, this Contractor shall secure his entire supply of each material from the same source so as to maintain the same quality and grading

*(Larger or smaller maximum size may be desirable for portions of the structure or for particular jobs.) Consult typewritten specifications for any change in grading of coarse aggregate.

throughout the work. Should it become necessary to change the source or characteristics of the materials used this shall only be done after additional proportioning tests have been completed for the new materials and subject to such safeguards as the Architect or Engineer may impose for the maintenance of the quality of the concrete in all respects.

10. ADMIXTURES AND SPECIAL CEMENTS.

Nothing shall be added to the essential ingredients of concrete (portland cement, fine and coarse aggregate, and water) without the approval of the Architect or Engineer in writing and then only such materials shall be added as have been thoroughly tested by reputable independent investigators so as to demonstrate their effect on the strength, elastic properties, permeability and permanence of concrete produced from materials such as are being used on this work.

No special cement shall be used in place of standard portland cement except upon the same basis of adequate test and known effect upon all vital properties of the resulting concrete.

Whenever such admixtures or special cements are approved for use on this work in this manner they shall be used in accordance with the manufacturer's instructions and in conformity with their use in the tests on which their acceptance is based.

11. REINFORCING STEEL AND INSERTS.

All reinforcing steel for this work shall be furnished and placed by this Contractor and shall be of the quality specified, and shall be fabricated and placed as required in Specification No. 503 of the American Concrete Institute.* All reinforcement shall be supported adequately in its designed location as specified therein. American Concrete Institute Specification No. 503 is hereby made a part of this specification and will become a part of the contract for this work when awarded.

All portions of the concrete work shall be provided with reinforcement (unless resting directly on the ground). Any gaps in the reinforcement as shown on plans shall be suitably filled, using not less than $\frac{3}{8}$ ∅ bars at six inches on centers in any case.

*In preparation.

12. FORMWORK.

Forms for the work may be made of wood, steel or other material which has been satisfactorily used on similar work for this purpose. All forms shall be mortar tight and sufficiently rigid to prevent sagging between supports. Surfaces of metal forms shall be free of marked irregularities, dents or sags. Knot-holes or broken places in wood forms shall be covered with metal patches. All formwork shall be so designed (cleanout openings at base of columns, at bottoms of deep girders, etc.) as to permit of ready cleaning after the reinforcement has been placed. For spans in the structure in excess of twenty feet the bottom of beams or girders shall be cambered allowing one-twenty-fourth of an inch rise per foot of span.

Wooden formwork shall be kept continually moist after being erected, so as to prevent the opening up of cracks in which dirt may lodge. Parafin oil shall be applied to forms immediately before the reinforcement is placed but in no case shall the oil be permitted to coat the reinforcement. Concrete shall be placed as soon as possible after the reinforcement has been placed and inspected, so as to prevent the collection of dust and dirt on the oiled formwork.

The design of the formwork shall include all necessary shores built in place in advance of concreting in cases where portions of the forms are to be wrecked before the concrete on them is ready to support itself. These shores shall not be disturbed in the wrecking of the adjacent formwork. No re-shoring will be permitted.

An experienced workman shall be employed at all times during the placing of concrete to watch the formwork and its supports and to strengthen any portions that may show signs of sagging, displacement or failure.

13. REMOVING FORMWORK.

This Contractor shall be solely responsible for the safety of the construction during and after form removal, and no act of the Architect or Engineer or of his representatives on the work shall relieve this Contractor of such responsibility. Subject to this limitation, forms for columns may be removed after one day, forms for slabs or other members whose span does not exceed

five feet nor eight times their depth and only for members which carry only their own weight or in which all superimposed loads are adequately supported by built-in shores, may be removed after three days. Other forms may be removed after seven days. The time referred to in each case is to be measured in days of good curing temperatures of not less than 60° F. (twenty-four hour average). At lower temperatures a longer period shall elapse sufficient to produce the same strength of concrete.

14. Patch formwork.

Forms for patches (where temporary openings have been left for any reason) shall be rigidly supported, being posted from the floor below or suspended by rods or bolts and not hung by twisted wires or other means that will permit displacement of the patch formwork and unsightly surfaces.

15. Concrete mixing plant.

Concrete for this work may be mixed on the job or at an approved central mixing plant. In either case the equipment shall be in first class working order so as to eliminate breakdowns and shall be replaced if necessary to insure satisfactory and continuous performance. A rotary batch mixer shall be used, of at least one-half cubic yard capacity and this capacity shall be increased if necessary so that the yardage of concrete to be placed at any one level above the foundations will be produced in not to exceed three working days, with a maximum requirement of two cubic yard mixers on very large jobs.

16. Measurement of the batch.

All materials, including water, shall be accurately measured by weight or volume for each batch of concrete. When wheelbarrows are used, the accuracy of measurement shall be maintained by striking off each load level full or by charging the wheelbarrow with measuring boxes that are struck off. Other measuring devices shall be calibrated and checked at frequent intervals. When additional water is used on account of weather (as, for example, on account of hot drying wind on a long haul in carts) it shall be accurately measured to produce the desired slump at the point of deposit of the concrete, and not added by guess or by operator's judgment.

The quantities of material for each batch for each class of concrete shall be computed from the mix as stated on the drawings (all concrete not otherwise shown or called for to be mixed with seven and one-half gallons of water per sack of cement) or determined by trial batches and preliminary tests as provided under articles 17 and 18 of this specification.

The quantity of water as finally determined for each batch shall include the free moisture on the surface of the aggregates. Tests shall be made as necessary to determine the amount of such surface moisture present in the aggregate. The maintenance of a uniform slump by this Contractor shall be considered a sufficient control of moisture variation and tests may be waived if such uniformity is secured on the job.

17. TRIAL BATCHES AND PRELIMINARY TESTS.

Class A concrete for this work shall be designed to produce a strength at 28 days in standard laboratory test cylinders of not less than 2000 lb. per sq. in.

Class B concrete—not less than 2500 lb. per sq. in.

Class C concrete—not less than 3000 lb. per sq. in.

Class D concrete—not less than 3750 lb. per sq. in.

Class E concrete—not less than 5000 lb. per sq. in.

When the materials to be used on this work have been approved by the Architect or Engineer this Contractor shall cause to be made, by an approved testing agency, a series of preliminary laboratory tests in strict accordance with the Standard Method of Making Compression Test of Concrete of the American Society for Testing Materials (serial designation C 39-27). These tests shall cover a water-cement ratio range beginning with eight gallons of water per sack of cement and including seven and six gallons per sack for Class A concrete; seven, six and five gallons per sack for Class B or Class C concrete; and seven, six, five and four gallons per sack for Class D or Class E concrete. These preliminary tests shall include at least six cylinders for each water-cement ratio used, three to be tested at 7 days and three at 28 days. The concrete for these cylinders shall be mixed to a consistency (and the slump recorded) suitable for placing concrete in this building. From the results of these tests (which may be judged from 7-day tests subject to checking, and to changing, if

needed, when 28-day tests are made) the water-cement ratio to be used in the work shall be determined for each class of concrete, to produce a strength (as shown by the tests) 15% above the required strength for that class, as given above, and the quantities of materials shall be determined by means of trial batches, using the actual mixing plant to be used on this work and making proper allowances for moisture, bulking of aggregates, etc. The final quantities of fine and coarse aggregate shall be limited only by the requirement of producing a thoroughly workable concrete, which does not segregate in transportation and placing, for the conditions of this job and by the further limitation that the volume of fine aggregate shall be not less than one-third nor more than one-half of the total volume of fine and coarse aggregate measured separately.

18. ARBITRARY MIXES.

For emergency cases, before the results of preliminary tests are available and for concrete not required to be stronger than Class C, the water-cement ratio may be taken as follows:

Class A concrete 7½ gal. of water per sack of cement—Approximate Mix 1:5¾.

Class B concrete 6¾ gal. of water per sack of cement—Approximate Mix 1:5.

Class C concrete 6 gal. of water per sack of cement—Approximate Mix 1:4¼.

The last figure in the notation for mix is the sum of the volumes of fine and coarse aggregate, measured separately. Trial batches shall be made on the job to determine the best distribution of this volume, as between fine and coarse aggregate, to give the desired workability and freedom from segregation in the concrete for this work.

19. TIME OF MIXING.

One full minute shall elapse between the time when all the material for any given batch is placed in the mixer and the time when the first concrete of that batch is discharged from the mixer. If eight or more sacks of cement per cu. yd. of concrete are used this time shall be increased to 1½ minutes, while if ten or more sacks of cement per cu. yd. of concrete are used, this time shall be not less than two minutes.

20. CONVEYING CONCRETE.

Concrete from central mixing plants shall be delivered to the hopper on the job in a thoroughly workable condition, without visible segregation either of water or of aggregates, ready for placing in the forms.

From the discharge hopper at the mixer or other place of first deposit on the job, the concrete may be conveyed by any means which will not result in segregation, to a hopper on the floor from which it shall be transported in buggies or wheelbarrows to its final position in the forms. Concrete shall not be discharged from a chute into the forms except in the case of massive members (such as footings) and then only, provided the maximum distance, to which the concrete is required or permitted to move from the end of the chute, shall not exceed three times the vertical thickness or depth of the member and that the edge of the fresh concrete is always kept well rounded.

21. PLACING CONCRETE.

At the time of placing concrete all formwork shall have been thoroughly washed and shall be clean and free of construction dirt and debris, all reinforcement shall be properly placed and supported and all inserts and openings shall be completely installed for a distance of at least thirty feet ahead of the concreting operation in all directions. Runways shall have been placed and the resulting dirt cleaned up and any steel disturbed shall be properly replaced. Formwork, if of wood or other absorbent material, shall have been wetted down so as to largely eliminate the suction. Column capitals or other points at which the washing water may gather shall be drained and the concrete shall not be deposited in standing water. In weather requiring heating of the fresh concrete in place, the salamanders or other heating devices shall be in operation before concreting starts. No snow or ice shall be left in the forms.

In columns, or similar slender vertical or slightly inclined members, the bottom shall be filled with mortar (concrete from which the coarse aggregate and much of the usual water has been omitted) which shall be sufficient in quantity and proper in consistency to work up with the concrete and to fill all spaces between closely spaced bars or between the steel and the form-

work. In girders or other similar members, in which the congestion of steel makes placing difficult, the lower part of the forms shall be filled with mortar in the same manner. This mortar, in either case, shall be placed immediately in advance of placing the concrete and shall not be permitted to dry out or set so as to lose its mobility before the concrete is placed on top of it.

Concrete shall not be dropped through reinforcing steel (as in walls or beams with top reinforcement) so as to cause separation of the coarse aggregate from the mortar on account of repeatedly hitting rods as it falls. In such cases hoppers, and, if necessary, vertical ducts shall be used in the wall forms or other means employed so that the concrete may reach the place of final deposit without separation. Concrete shall be deposited in small amounts at many points and shall not be required or permitted to flow along the forms, or from beam forms into column or wall forms.

Concrete shall be worked around the reinforcing rods, inserts, etc., and against vertical forms as it is being placed, so as to produce smooth dense surfaces and complete filling of all spaces within the forms but care shall be taken not to over-spade the concrete so as to cause segregation locally. Concrete being placed with a very stiff consistency (as in paving base or in sloped footings concreted without forms) shall be consolidated by tamping or vibration.

22. Construction Joints.

All the concrete in vertical members (such as columns or walls) shall have been placed at least two hours before any concrete is placed in the beams or slabs directly over such columns or walls. This interval may be increased if desired (overnight, for example) but necessary precautions shall be taken to insure that the new concrete bonds to the older concrete if the interval exceed thirty hours or if the weather is hot and drying. In any case any excess water or fines that may rise to the top at a horizontal construction joint shall be removed and the concrete cut away as necessary to insure strong, dense concrete at the joint.

Construction joints in beams and slabs shall be vertical and shall be located close to the center of the span, unless a beam intersects a girder at this point, in which case the joint in the

girder shall be offset a distance equal to twice the width of the beam and inclined reinforcement provided to take the shear across the offset construction joint. Construction joints shall be made with a key at the center of depth and with reinforcement near each face of the member; additional bars, at least 60 bar diameters in length being provided where steel is lacking in either face of the member cut by the construction joint.

23. CURING OF CONCRETE.

Concrete, after taking its initial set, shall be protected from drying out at all times during the first seven days after it is deposited. If the concrete is so located as to require especial water tightness this curing period shall be increased to twenty one days. Protection may be afforded by replenishing the supply of moisture to offset losses by evaporation or by sealing in the water carried by the concrete so that it cannot later evaporate. All portions of the structure shall be kept moist and warm simultaneously for the full curing period of seven or twenty-one days and any portion of the time during which either moisture or warmth is lacking shall not be counted as effective for curing.

24. COLD WEATHER PROTECTION.

Artificial heat shall be provided and effective enclosure maintained, whenever necessary, to insure that the air in contact with concrete, for a period of seven days after placing, shall not fall below 50° F. for any considerable time. The temperature within enclosures shall not exceed 100° F. Moisture shall be provided within the enclosure as required by article 23.

When necessary to insure that the fresh concrete shall reach the forms at a temperature of not less than 50° F. the materials (water only in moderately cold weather and aggregate also in very severe weather) shall be heated. The concrete may be heated in the mixer by any means that will not impair its quality. Dependence shall not be placed on salt or other chemicals to prevent concrete from freezing. No frozen materials or material containing lumps of snow or ice shall be used. Manure shall not be applied directly to concrete when used for protection.

25. WATER SUPPLY.

An adequate supply of water for cleaning formwork and for curing concrete shall be installed so as to be available before con-

creting starts at any level and for at least the period of curing as required by article 23.

26. PROTECTION OF CONCRETE WORK.

Concrete shall be protected from washing and from the addition of excess water in the concrete during stormy weather, until such time as it has sufficiently hardened to resist washing or penetration. One extra sack of cement per cu. yd. of concrete shall be added to maintain the required water-cement ratio and surface water shall be drained away from the fresh concrete during heavy rains.

Concrete work shall be protected from injury during the wrecking of formwork and from injury due to the storage or movement of materials in the building during construction.

27. CEMENT FLOOR FINISH AND UNDER-FINISH.

Cement floor finish or under-finish (cement finish shown on plans to be covered by linoleum or other surfacing material), if less than one and one-half inches thick, shall be placed as soon as the structural concrete has hardened sufficiently for workmen to walk on it, or a dry mixture of sand and cement in the proportions of the mortar in the concrete may be dusted on the surface of the concrete before initial set has occurred. In either case the method used must result in the formation of a mortar surface layer of uniform consistency (about four-inch slump) without excess water, which shall be darbied to a true surface and trowelled later to a dense smooth finish. The surface shall not be gone over more than twice with a steel trowel.

Stair finish shall be handled in the same manner as floor finish.

Mortar for floor finish or under-finish shall be made with the same proportions of cement and sand as is used in the concrete to which the finish is to be applied. In no case shall the volume of cement exceed 40% the volume of the fine aggregate.

28. CINDER CONCRETE FILLING.

Where cinder concrete is called for on the plans as a filling material (under floors or roofs, for example) it shall be mixed in a rotary batch mixer and placed at a very stiff consistency. The amount of cement used shall be sufficient to produce a concrete that will stand up under ordinary foot traffic without noticeable disintegration. Expansion joints shall be provided to take care

of temperature movements in roof or other fills subject to more than 40° F. change in temperature, or subject to changes in moisture content. Open expansion joints (covered with copper strips nailed at one edge with bronze nails) approximately one inch wide shall be provided in both directions at intervals of 20 to 30 feet (preferably on column center lines) extending the full depth of the filling.

29. CONCRETE SLABS ON GROUND.

Concrete floors shall not be placed directly on the ground, other than sand or similar material, unless a waterproofing layer is present. One-course concrete floors on ground, sidewalks and parking strips, shall be laid on top of a plain cinder filling at least five inches thick, tamped and finished accurately to the required grades of the underside of the concrete. They shall be of Class A concrete of the thickness shown on plans (but not less than five inches thick). They shall be finished as specified in general for floors or as called for on plans.

Open joints (⅞ inch wide) shall be left between such a floor slab and the enclosing walls and columns and this joint shall later be caulked with asphalt mastic. In case the floor slab is exposed to more than 40° F. variation in temperature, or is subject to changes in moisture content, or is more than 100 feet long in any direction, similar joints shall be made at intervals of not to exceed one hundred feet and caulked in the same manner.

Where a two-course waterproofed floor on the ground is called for, the cinder fill shall be omitted. The lower course shall be of Class A concrete of the thickness shown on plans (but not less than four inches thick) and shall be wood floated to a smooth surface accurately pitched to drains or level as shown on plans. On this surface a membrane waterproofing shall be placed, consisting of two layers of fifteen-pound asphalt saturated cotton membrane laid in three moppings of hot waterproofing asphalt. Waterproofing shall be carried to the reinforcing steel in columns and walls and shall extend above ground water level, to insure a complete exclusion of ground water. The upper course shall be four inches thick, of Class A concrete, reinforced with welded wire fabric weighing not less than 70 pounds per 100 square feet.

The top of this slab shall be finished as specified in general for floors or as called for on plans.

Cement finished floor (either one-course or two-course) shall be completely covered and protected from rain until concrete is hard.

30. FOUNDATION WATER.

Foundations shall be freed of water at the time concreting starts. Where water from the surrounding ground runs into the footings, it shall be removed by means of pumps oustide the footing or footings, in which concrete is being placed. Sheeting around footing excavation shall be driven sufficiently below the bottom of the concrete work to prevent any sand shoulder at the edges of the excavation that would reduce the covering of concrete beneath or outside of the reinforcement in this region. Footings shall be full size as called for on drawings at all points.

In deep wells, or where, for any reason, the water cannot be removed, concrete shall be placed only by the tremie method. In such operations the discharge end of the tremie shall be kept continuously submerged in fresh concrete and the shaft of the tremie shall be kept full of fresh concrete well above the water level at all times. For such work the concrete shall be made with at least one sack of cement more per cubic yard of concrete than is required for concrete of the same class placed under ordinary conditions. The concreting shall proceed without interruption until the top of the fresh concrete is well above the water line and the accumulation of fines shall then be entirely removed and wasted until well proportioned concrete is found.

DISCUSSION BY THE AUTHOR

The preparation of a specification for general use by architects and engineers in all parts of the country involves much more than the preparation of a specification for a particular structure. This specification has been submitted not only to those named in the document as critics but also to several others—some deliberately selected because of a not-too-great attachment for scientific concrete. This process has revealed a surprisingly general appreciation of the requirements for the manufacture

of good concrete in the field. If I may summarize and paraphrase my conferences with representatives of leading contractors in the Chicago district, the "average" contractor would say:

This specification calls for the quality of concrete that we aim to produce on our work. In the hands of an experienced and practical superintendent it would work little or no hardship on our contracts. If this specification were generally adopted, however, we must face the probability that it would be enforced on many jobs by a stiff necked, impracticable, 1929 college graduate, who could use it to work hardships on us, and we would therefore add to our price to cover this contingency. We realize that this specification would correct certain abuses that still persist on construction work.

With this criticism in mind I have examined and discussed lengthily the clauses in this specification on which the inexperienced inspector may "hang" the contractor. Wherever possible I have modified such provisions, not now generally enforced, to remove this difficulty, as far as possible without losing the assurance of a high grade concrete. My own experience includes long service on the contractor's side of this argument and I believe that I understand and sympathize with his position. But first and finally my aim in preparing this specification has been to insure good concrete on the job under reasonable enforcement of the specification.

I would remind estimators that the determination of concrete strength from preliminary tests on a water-cement ratio basis permits marked savings in cost, as well as better quality, as compared with the old arbitrary mix specification now happily passing off the construction stage. This method and this saving is permissible only under the assurance that the strength of concrete secured in the tests will be likewise secured on the job. Several of our leading and most prosperous contractors on concrete work are already following essentially the same specification and have found no increased cost nor hardship in it, when all factors are finally balanced. I have used this specification, or a slightly more severe one, for several years with no observable tendency toward higher bid prices nor difficulties in its reasonable enforcement.

Brief comment on some of the "unusual" specification clauses may be interesting. The requirement that cement be held in sealed storage until seven day tests have been completed may appear sophomoric. There is good evidence that such precautions

are needed and that tests of cement without such a provision may be useless. Practically it would mean (if this specification should be generally adopted) that dealers should install a regular sampling and testing service thus making sure that all their deliveries, instead of most of them, are up to standard.

The requirement that a constant source of supply for all materials be maintained on each job is also a hard provision for material dealers to "see." The practice of swapping orders and of delivering to the job whatever material is handiest, is doubtless good business for the material dealer, but it costs the contractor far more in labor of handling concrete (to produce proper results) than it saves the dealer. Economical concrete placing (no less than uniform concrete quality) requires that the consistency of the concrete be uniformly maintained at just the right flow for easy placing without segregation. Variation in the grading of aggregate or in its source almost invariably upsets this condition and repeated variations make quality concrete most difficult, if not at times impossible, to obtain. This provision is vital to this specification.

Admixture manufacturers and salesmen will not enthuse over article 10. We have meagre reliable information on most admixtures—practically nothing but salesmen's loose talk on others. The instructions on the printed label are sometimes absurd. Any product that has been on the market as long as this ought to be less of a secret-formula patent medicine and more of a staple article. The tests that are known are none too encouraging and many large corporations which have made tests for their own information and have decided to dispense with most admixtures as a result, are unwilling to publish their data for the benefit of the rest of us. I feel that this specification contains the only sensible provision that can be made in the present situation. If generally accepted it should lead to the accumulation of adequate and reliable test data to supplement the widely variable data of experience now generally circulated—the favorable opinions being circulated by salesmen and the unfavorable by other salesmen.

Article 21 contains a particular impractical requirement for placing concrete in reinforced walls and doubly reinforced beams that I cannot decide to strike out notwithstanding. Why mix

concrete expensively and transport it carefully to avoid segregation and then finally unravel it into stone and mortar pockets in the forms? That procedure may be eminently "practical" but it is not sensible and it does not result in good concrete in such members. The added expense of good work is very slight, provided the job is organized properly and the day's work intelligently planned.

"Curing" concrete (keeping it moist and comfortably warm) for seven days has worried some contractors who fail to realize the importance of proper curing on both the strength and permanence of the concrete. In summer when nature provides the heat, the cost of sprinkling (or of sealing in the water of the concrete) is very slight. In winter enclosing and heating is undoubtedly expensive but since we already enclose and heat for a shorter period the added cost involved is much less than it would seem at first glance. At present many specifications call for only three days of proper curing in winter. Seven days of proper curing will insure the development of a major fraction of the ultimate strength in the concrete, will permit of early formwork removal and will remove any chance of collapse. As against the cost of an extra story of formwork in a multi-story building, the cost of seven day curing is very small and in some cases more than one story of formwork can be saved.

Keeping wood formwork continually moist from the time of its erection is another somewhat unusual provision. It greatly improves the final surface obtained on the concrete. It largely eliminates lateral movement of forms that throws elevator shafts and lintels out of plumb, causing expensive cutting later. These items far overbalance the very slight expense involved in sprinkling.

Doubtless individual contractors will "balk" at other provisions also. My answer is, simply, that while concrete has performed amazingly in spite of gross abuses in the past, it is entitled to some consideration. This specification is intended to result in a job of concrete that is sound and good in all its parts—a worthy job but not at all a fancy job. Careful study will show that many requirements common in specifications are absent from this one, for the reason that they do not appear necessary for the production of good concrete. "Dusting" on a cement finish is one

such item, often prohibited. I am satisfied that equally good work may be secured by this method—and that much damage may be done fresh concrete by wheeling over it heavy carts of mortar when it is only a few hours old. This method, incidentally, is much less expensive than the older standard, and does not interrupt the concreting operation.

I shall be interested to have the discussion of many other contractors and superintendents and specification writers to the end that this document may be further improved for practical use in the manner intended. I shall also be glad to know of the experience that others may have in actually using this specification in their work, which is a much better test of the quality of this document.

DISCUSSION BY A. S. DOUGLASS

I wish to approve herewith the above specifications as the best available specification at this time and recommend its adoption by the American Concrete Institute, but in so doing wish to make comment on that specification, with a further recommendation that the Institute consider the necessary work of revising it along the lines which I will indicate.

It has always been my thought that a general specification should consist, as far as suitable, of references to standard detail specifications and that only such additional language should appear in the general specification as cannot be found in the standard detail specifications. More specifically, I feel that all reference to concrete mixing and proportioning practice, to portland cement, to aggregates, to reinforcing steel, should be limited strictly to reference to accepted existing specifications, and I find in this specification many paragraphs devoted to detailing of matter which, it seems to me, should appear only in the manner I have above described.

Were I to attempt, however, to prepare a specification drawn along these lines I should immediately encounter the following situation:

In the 1929 directory of the American Concrete Institute, page 12, under "A. C. I. Standards," in the middle of the page reference is made to "Standard Specifications for Concrete and Reinforced Concrete." Further down the page reference is made to "Stand-

ard Specifications for Concrete Floors," and still further down to "Tentative Purchase Specifications For Concrete Aggregates." It is my thought that the proper procedure would be for the specifications under discussion to limit itself, on these subjects, to reference to these specifications, if they are still valid. However, I find the first Standard above referred to is dated August 14, 1924, and a brief study of that Standard shows it not to be strictly up to date with respect to modern field practice. Further, many districts, of which Detroit is one, have gone to considerable effort to perfect a local specification for aggregates suitable to the particular district in question. I feel that provisions in the specification under discussion should recognize these varying local specifications and make them applicable to the General Specification by reference. For obvious reasons, it is impracticable to make a single national standard aggregate specification.

From the foregoing it appears, to draw a general specification of the sort being discussed, and to conform with the ideal of the writer, it would be necessary to bring up to date all constituent specifications which should be referred to. Mr. Lord, in my correspondence with him, has called attention to the desirability of having this specification a complete working document. This should be accomplished by reference and quotation from constituent specifications. If done in this manner it would insure the uniform specification standards for which I am seeking.

In all the foregoing the purpose I have in mind is to avoid variation in wordings, variation in ideas, and to afford contractors and vendors, as nearly as possible, a definitely comparable basis for estimating their work. I realize in making these comments that it is quite idealistic but I am sure, nevertheless, that the accomplishment of this ideal would be in the direction of clarity and standardized practice, the benefits of which seem obvious.

There is another problem presented in this specification which I should like to mention for consideration, even though I must admit that I can offer no good solution. On page 8, paragraph 13, the first sentence places entire responsibility on the contractor and the balance of the paragraph specifies a procedure which must be followed, subject to the limitations of the first sentence.

It seems to me that a matter of this sort is one of the most difficult to handle in a way to meet all objections. The question seems to be—shall full responsibility be placed on the contractor and stop at that, or shall the engineer specify, step by step, what the contractor may or may not do? Both extremes have their undesirable aspects, and the more I ponder on the solution the less sure I am that I can evolve an entirely suitable one.

DISCUSSION BY A. B. MacMILLAN

I have studied the Specification prepared by Arthur R. Lord carefully and approve it generally. There are two items, however, in which our practice is at variance.

First, "Cold Weather Protection"—our standard specification for this purpose is as follows:

If concrete is mixed and placed during cold weather, that is, when the temperature is below 35 degrees F., at any time during the day or night, of if any part of the aggregate contains frozen particles, regardless of the outside temperature which prevails at that time, the aggregates and the water shall be heated uniformly throughout their masses to a temperature of not less than 50 degrees F., and shall be not less than the above temperature immediately before being placed in the mixer.

When the temperature during the day or night drops below 35 degrees, canvas screens or other approved means of protection shall be erected around all concrete work and heat from salamanders or other sources shall be continuously supplied for at least seventy-two (72) hours from the time the concrete is poured, in amounts sufficient to insure a temperature of not less than 40 degrees F. being maintained in the air surrounding the concrete work.

Care shall also be taken to insure that the temperature of any new concrete surfaces adjacent to the source of heat does not exceed 100 degrees F.

The other requirement with which I cannot agree, relates to the use of tremies. A tremie is excellent but we have found that a special bottom dump bucket which must be lowered until the bottom is resting on the prepared surface or on the surface of concrete already poured before it can be tripped gives equally good results and is much more practical for use in some locations than a tremie would be. I recommend that the use of such buckets be permitted.

Readers are referred to the JOURNAL *for March, 1930, for further discussion.*

Permissible Openings In Construction

Report of Committee 306

BY ALBERT SMITH,* AUTHOR-CHAIRMAN

Mr. Smith *was assigned the task of writing a report contributing to rational practice with respect to openings in concrete construction, in which there have been many abuses—"Conditions requiring unframed openings; effect of openings of various sizes on stresses and deflections; effect of location of opening; special reinforcement about openings; shrinkage stresses at openings; early form work removal; recommended practice in design." This partial or progress report, prepared by Mr. Smith, has been approved by A. E. Lindau and Prof. G. A. Maney as the two critic members of the committee.*

—Editor.

In any concrete floor there is no point at which there is not either shear or moment, and no area in which both are not present.

Any hole of finite area therefore, causes a disturbance in the lines of stress, and if the opening is large the increased stresses at the edges and corners of the opening may largely exceed the safe units.

Exact computation of the stresses thus produced is very difficult, and in nearly all cases unnecessary. Where the openings are large approximate computations can be made readily, and where openings are small office rules can be made to provide for the stresses.

Holes, whose major dimension does not exceed three times the thickness of the slab, require no special provisions except where

*Smith & Brown Engineers, Inc., consulting and designing structural engineers, Chicago.

they occur within the middle half of the compression length of the top flange of a beam or joist, and then only when they remove a portion of the tributary flange.

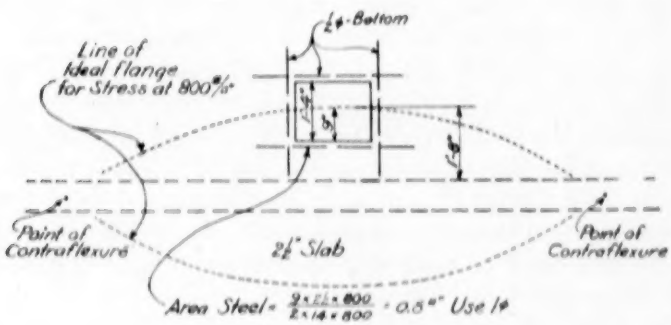
When small openings are so located as to rob the flange the average stress in the diminished flange should be somewhat less than the design unit.

Design specifications permit the inclusion in the computed flange of a width of 8t of slab on each side of a double flange beam and 6t of slab in a single flange beam. The compression in the slab does not however become zero at a distance 8t or 6t from the face of the beam. It extends in diminishing amount to the mid-point between beams. Any opening therefore causes the detouring of considerable stresses around the edge of the opening.

Where the opening is larger than 3t its edges should be reinforced by rods of a size depending on the thickness of the slab.

Where an edge of such opening lies within 8t or 6t of the face of the beam, in addition to the concrete and steel required for flange stress, the edge parallel to the beam should be reinforced with steel adequate to carry ½ the expected compression stress in the tee section cut away.

Thus—



If such a hole occurs where the flange stress is less than maximum, the extra edge steel may be correspondingly reduced. The rods on the other edges of the opening carry in tension the

bending from the load on the band of slab cut by the opening and, in addition, help resist the shears from the detoured stresses.

Where a beam or joist has an abrupt change in height of top flange, stirrups must be provided to resist the horizontal and vertical shears developed by the change of course of the compressive stress. Where in a tee beam the low tee is prolonged so that the high tee laps over the lower not less than five times the drop in floor level no special reinforcing is required. If the drop occurs at a point in the length of the beam where the moment stress is low no special reinforcing is required. It is assumed here that the normal requirements for diagonal tension have been met.

Embedded vertical pipe sleeves, which do not interfere with the proper placing of the moment steel, will not necessitate additional provision for diagonal tension.

Embedded horizontal pipe sleeves, if not greater in diameter than d/3, and if so placed that the top is at least d/4 from the surface of concrete, need no special reinforcement, if net concrete area is adequate for shear. If the top of the sleeve is less than d/4 from the surface of the concrete at a point along the beam where the positive moment is as much as half the maximum, such a sleeve shall be wrapped with mesh. If the diameter of the sleeve is greater than d/3, special stirrups shall be provided to carry the shear across the sleeve.

If tin sleeves are used instead of pipe sleeves, the full section lost shall be counted as lost, whatever the size of the sleeve.

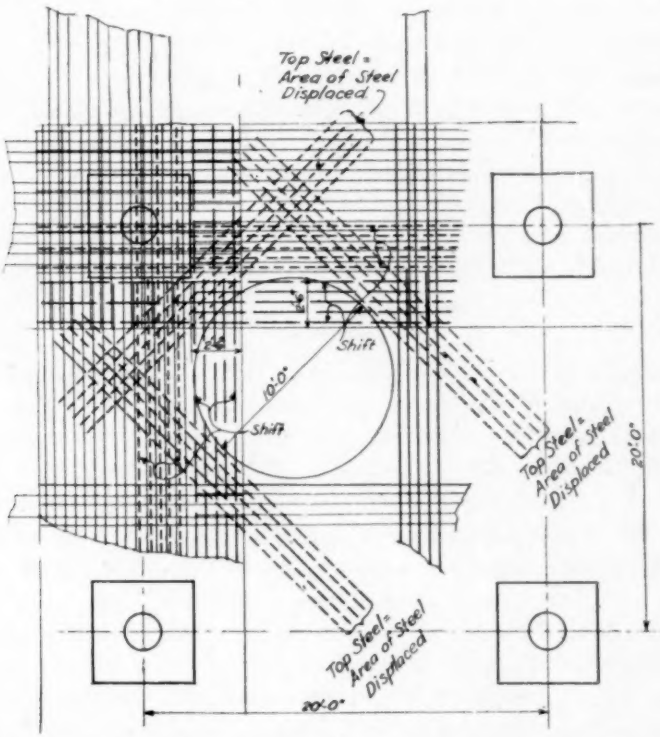
Any hole cut in slab or beam stem shall be assumed to have robbed the section of an area two inches greater than the actual dimension of the hole. Where such holes are cut in beam stems the net shear in the remaining section should be much less than the code unit. Where diameter of hole exceeds d/4, or being less than d/4 still causes the shear stress to be 75% of the design unit, the hole shall be lined with an iron sleeve packed in hammered dry grout.

Holes in flat slabs produce additional stress in two edges if reinforcing is in one direction and on four edges if it is two-way. If the edges of the hole receive a concentrated load this effect is increased. Special steel must be placed to resist the increased stress. In the design of the slab the load from the interrupted

bands may be assumed to be carried by the adjacent slab in a width of 5t.

In a Flat Slab Floor, holes in the A bands must not rob the band of more than 25% of its width, and if less than 25%, the interrupted band steel shall be placed in close spacing as near as possible to the edge of the hole. In moderate spans and light live loads the concrete stress of the band will not be dangerously large. The continuity of contiguous bands shall be increased by top steel on the 45 degree lines.

Where in long spans heavy live loads produce a concrete stress near the design unit compression reinforcing should be introduced at the edge of the opening.



If the hole cuts more than 25% of the band, either the drop shall be prolonged between the columns or the opening framed with special beams.

Holes within the drop shall similarly be framed with additional steel and in two directions. If such holes exceed 25% the width of the drop the opening shall be framed with beams.

Pipe holes in both drop and capital must be framed with pipe sleeves.

Openings, which rob the capital of 25% of its bearing edge under any band shall be framed with special brackets.

Readers are referred to the JOURNAL *for March, 1930, for discussion which may develop.*

Portland Cement Stucco Finishes

Report of Committee 401

BY W. D. M. ALLAN,* AUTHOR-CHAIRMAN

In the preparation of this report the Author-Chairman has had the active cooperation of the critic members of the committee: F. O. Anderegg, Mellon Institute of Industrial Research, University of Pittsburgh; C. S. Downs, manager Art Stone Products, Inc., 52 Vanderbilt Ave., New York City; J. C. Pearson, assistant to chemical engineer, Lehigh Portland Cement Co., Allentown, Pa.; Allan Stubbs, California Stucco Products Co., 930 Grant Bldg., Pittsburgh, Pa.; Arthur Ware, architect, 1170 Broadway, New York City. The report has been subjected to their criticism and is approved by them subject to a footnote inserted as a result of suggestions from Dr. Anderegg.—Editor.

INTRODUCTION

The assignment to Committee 401 was to prepare a summary of available information on the best practices governing portland cement stucco finishes. Recent years have witnessed considerable development in this field with the result that earlier practices have had to be changed to meet present conditions.

A review of available test data, with the exception of the work done by the Bureau of Standards, does not disclose any considerable amount of scientific research work upon which to base a recommended practice. The present recommendations seem to be largely the result of opinions drawn from the experiences of those closely connected with the stucco business.

While not definitely a part of the Committee's assignment, it wishes to point out that there is a wide disparity between the

*Manager, Cement Products Bureau, Portland Cement Ass'n., Chicago.

recommendations for good stucco construction and the practice followed in the field. Those who are interested in improving stucco conditions must devote more time to getting the architect, contractor and plasterer familiar with the requirements of stucco construction.

In connection with the demand for color in architecture, stucco fills a definite place in the building material field. Color and texture are the peculiar advantages of portland cement stucco, which along with its durability and adaptability, make it an unusually effective method for the expression of beauty and individuality.

GENERAL

Successful work depends in a very large measure upon the suitability of the structure over which the stucco is placed. If the structure moves from any cause, the strain placed upon the stucco slab may cause it to crack, even though best practices are followed in the selection of materials and the application of the stucco itself. There is no doubt that improper underconstruction paves the way for a large majority of stucco failures. In the successful use of stucco the following fundamentals must be provided for:

1. The building must be rigid and designed for stucco.
2. The stucco must be applied to a suitable base.
3. The stucco mortar must be properly proportioned and thoroughly mixed from carefully selected materials.
4. It must be applied by workmen familiar with the properties of portland cement mortars. So far as available information justifies definite conclusions this summary is offered as the Committee's recommendations covering the application of portland cement stucco. There are several important points upon which there is a difference of opinion. In so far as it is possible the Committee has stated the leading differences and has pointed out wherein additional test data are necessary.

In any general discussion of stucco it should be kept in mind that there are two general types of construction. Stucco is either a thin slab of concrete bonded to and an integral part of the backing, or it is a thin reinforced concrete slab attached to but not an integral part of the backing.

DESIGN

Keep water from getting back of stucco is the first requirement of stucco design. Adequate flashing at all places where water might get behind the stucco slab and the use of drip grooves on all moulds, caps and sills is essential to satisfactory stucco performance. Stucco should be confined to vertical surfaces and the stucco should be stopped at a line approximately 6 inches above the grade, preferably at a masonry water table. This is to prevent ground water from getting back of the stucco and also to reduce the danger of water splashing onto the stucco causing discoloration and possible disintegration due to frost action.

CONSTRUCTION

Roof gutters, down spout hangers and all other supports of any kind should be in place previous to the application of any stucco in order to avoid breaks in the surface and to get watertight construction.

Masonry Walls—Walls of concrete masonry, hard burned clay tile and hard or medium burned clay brick are satisfactory for the direct application of portland cement stucco. The rigidity of masonry walls makes them superior to frame walls as backing for stucco.

Masonry walls should be laid in mortar not leaner than 1 part cement to 1 part lime to 6 parts of sand. Joints should be cut back even with the face of the wall or slightly raked. The surface to which stucco is to be applied should be rough and of coarse texture and be free from dust, dirt and loose particles. Provision of adequate mechanical key is necessary where the absorption of the base is low, making it difficult to get a strong suction bond. Wood lintels should not be used over wall openings in masonry construction.

Monolithic Concrete—Monolithic concrete walls that have rough surfaces are suitable bases for the direct application of portland cement stucco. When the surfaces are not rough enough to provide physical anchorage for the stucco, it is necessary to provide additional mechanical key. The following methods are frequently used:

1. Old monolithic concrete walls

a. Old monolithic concrete walls can be roughened with bush hammers or

similar tools, after which they are washed with water to remove all dirt and loose particles.

b. Washing with a solution of 1 part muriatic acid to 6 parts water frequently will etch the surface sufficient for mechanical bond. A wall to be acid washed should first be drenched with water to prevent the absorption of the acid and limit its action to the surface. Several applications of the acid treatment may be necessary to provide the desired results. After the wall has been acid treated, it should be thoroughly washed with water to remove all traces of the acid and loose particles.

2. New monolithic concrete

a. New monolithic concrete can be roughened with a heavy wire brush or other scoring tools if the forms can be removed early enough. Care must be taken not to remove the forms, however, until the concrete is self-sustaining. Soap or oil coating should not be used on forms for monolithic concrete that is to receive stucco as they are likely to interfere with a satisfactory bond.

b. Another effective method of providing rough surfaces to new monolithic concrete is by the application of a special large mesh burlap fabric tacked to the form face. When the forms are removed the fabric remains embedded in the surface and should be stripped off immediately before the surface concrete has a chance to dry. This leaves a roughened surface that provides an excellent mechanical key for the first coating of mortar.

c. Use of proprietary compounds painted on the forms before the concrete has been placed retards the hardening of the surface mortar. As soon as the forms are removed the surface mortar is brushed off with a wire brush and the

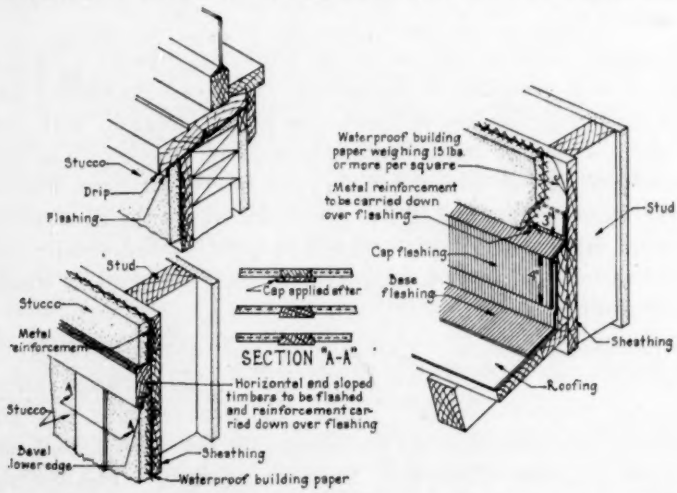


FIG. 1—FLASHING DETAILS (UPPER LEFT) FOR WINDOW SILL; (LOWER LEFT) FOR HALF-TIMBER CONSTRUCTION; (RIGHT) WHERE PORCH ROOF OR DORMER ABUTS A STUCCO WALL.

wall washed, exposing the aggregate. The brushing must be done early or the surface mortar will become hard and very difficult to remove.

Wood Frame—Wood framed structures, which are to be stuccoed, must be well braced to provide rigidity. Studs should be placed on 16″ centers when sheathing is used and on 12″ centers for backed plastering or open frame construction. The studs should be continuous from sill to rafter plates to avoid points of weakness in the wall of construction. Diagonal braces of 1 x 6-inch lumber, 6 to 8 feet long let into the studs on their inner faces at upper and lower corners of each wall and bridging between the studs at least once in each story height, are necessary for proper rigidity. Double studding should be used at all corners and angles and around all windows.

There is considerable difference of opinion as to the value of sheathing on frame stucco structures. The insulation which is furnished is probably the chief advantage. If sheathing is used, it should be placed horizontally across the studs and not diagonally although in many sections of the country diagonal sheathing is used on account of the increased bracing which it provides. Sufficient rigidity, however, will be obtained by using the system of bracing described above and a considerable saving will be effected in both labor and material by placing the sheathing horizontally.

Frequently the shrinkage and warping of lumber used in wood frame construction is responsible for damage to the overlying stucco slab. It is advisable to use only well cured lumber. All joists, studding, bracing and sheathing must be securely nailed.

In view of the importance of insulation considerable attention is now being given to the use of various types of insulating boards in place of wood sheathing. In general it is permissible to substitute any approved insulating board for wood sheathing providing the frame is adequately braced. When sheathing of any kind is used, it should be covered with a good grade of waterproof building paper, applied in weather-board fashion with each strip lapping the strip below and all flashing at least 2 inches, and all end or vertical joints lapping at least 12 inches and tightly nailed. The paper prevents the sheathing from robbing the stucco of its moisture and also serves as insulation.

In certain sections of the country, notably California and

Florida, open construction in stucco work is used. In this type of construction sheathing is dispensed with, building paper being fastened directly to the studs. To prevent the paper from tearing, wires are stretched across the face of the studs at 8″ intervals before the paper is applied.

There are several types of paper backed metal bases on the market which are applied directly to the studs. They have the advantage of paper, furring and base being applied in a single operation. The paper is generally fastened to the reinforcement sufficiently loose so that the pressure of the trowel in applying the mortar causes the paper to bulge enough to permit practically all strands of metal to be thoroughly embedded. In selecting paper backed metal reinforcement, particular attention should be given to the method by which the paper is fastened to the reinforcing. There should be at least 3/8″ between the paper and the back of the metal when the scratch coat of mortar is applied.

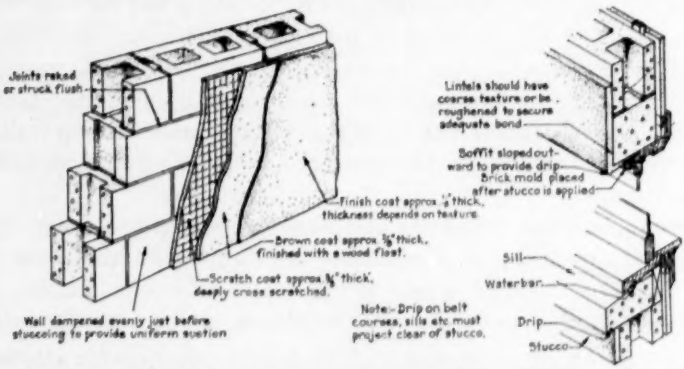

Joints raked or struck flush
Finish coat approx. 1/8" thick, thickness depends on texture
Brown coat approx. 3/8" thick, finished with a wood float.
Scratch coat approx. 3/8" thick, deeply cross scratched.
Wall dampened evenly just before stuccoing to provide uniform suction
Lintels should have coarse texture or be roughened to secure adequate bond
Soffit sloped outward to provide drip
Brick mold placed after stucco is applied
Sill
Waterbar
Drip
Stucco
Note—Drip on belt courses, sills etc. must project clear of stucco.

FIG. 2—STUCCO ON CONCRETE MASONRY. (LEFT) CONCRETE TILE OR BLOCK WALL; (UPPER RIGHT) DETAIL OF WINDOW HEAD; (LOWER RIGHT) DETAIL OF WINDOW SILL.

In back plastered construction neither sheathing or building paper are used. The metal reinforcement is fastened directly to the studs. The coat of back plaster is usually 3/8″ or more thick. Construction of this type performed very creditably in the recent Florida storms. However, walls in both open and back plastering construction lose the insulating value of sheathing and to compensate for this in regions of wide temperature range a layer of insulating material must be placed between the studs.

Metal reinforcement for stucco should be of a large mesh type of expanded metal or wire fabric. Its minimum weight should be 1.8 pounds per sq. yd. Opening should be not smaller than ¾″ square, nor larger than 2″ square. Large openings in the reinforcement are necessary so that the mortar may be pushed through to the backing completely embedding the metal. In back plastered work reinforcement with small mesh is necessary in order to hold the fresh mortar. The weight should be not less than 3.4 pounds per sq. yd.

Reinforcement should form a continuous network of metal over the entire surface. All laps should be at least 1 mesh wide and tightly wired with soft annealed wire. If the laps are meshed together carefully, the use of butt joints gives a greater uniformity in the section of the reinforcement. Reinforcement should be returned at all corners one stud width in open and back plastered construction and six inches in sheathed construction. Thick, bulky laps, especially when insecurely tied, are a source of trouble in stucco work.

It is essential that metal reinforcement be furred out not less than ⅜″ from the supporting base. Furring should locate and securely fasten the reinforcement as near the center of the stucco slab as possible. At the same time no type of furring should be used which by its nature would materially reduce the thickness of the slab under the furring and thereby induce cracking. Metal and wood furring strips are to be discouraged. Nails which carry a metal furring device are recommended above any other types of furring. Several such nails are now on the market. Large mesh reinforcement properly furred out with these nails makes it impossible not to completely embed the metal.

Discussion—There is a tendency to promote reinforcement devices designed to save mortar and labor of applying it. Any plaster saving device that leaves part of the reinforcement exposed while the remainder of it is embedded should be viewed as dangerous. A minimum of ⅜″ of the material at the back of the metal is essential for protection against corrosion on all exterior work and interior work exposed to moisture.

Proportions and Mixing—The present tendency is towards stucco mixes as lean as can be worked. For base coats a proportion of 1 sack of cement to 3 cu. ft. of aggregate and 10 pounds of hydrated lime is widely used. The size and the grade of the aggregate have an important bearing upon the quality of the

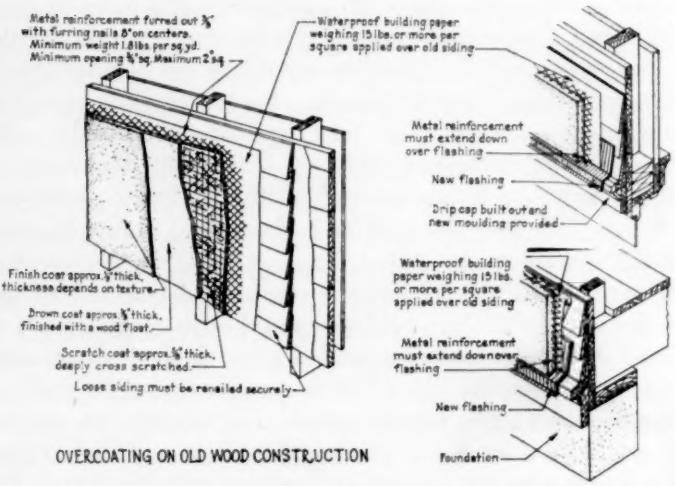

Metal reinforcement furred out ⅜" with furring nails 8" on centers. Minimum weight 1.8 lbs. per sq. yd. Minimum opening ½" sq. Maximum 2" sq.
Waterproof building paper weighing 15 lbs. or more per square applied over old siding
Metal reinforcement must extend down over flashing
New flashing
Drip cap built out and new moulding provided
Finish coat approx. ⅛" thick, thickness depends on texture
Brown coat approx. ⅜" thick, finished with a wood float
Scratch coat approx. ½" thick, deeply cross scratched
Loose siding must be renailed securely
OVERCOATING ON OLD WOOD CONSTRUCTION
Waterproof building paper weighing 15 lbs. or more per square applied over old siding
Metal reinforcement must extend down over flashing
New flashing
Foundation

FIG. 3—STUCCO OVERCOATING. (UPPER RIGHT) DETAIL OF WINDOW HEAD; (LOWER RIGHT) DETAIL OF WATER TABLE.

stucco and the ease with which it can be handled. All the aggregate should pass the No. 4 sieve. As much as 5% passing the 100 mesh sieve is desirable and more than 10% is to be avoided. Care should be taken to select aggregates that are free from injurious amounts of silt or other impurities.*

Discussion—Mixes varying from 1 to 1½ to 1 to 4 have been recommended and used in different parts of the country for under-coat construction. The more fines in the mix, whether the fines be cement or fine aggregate in the form of pulverized stone or special admixtures, the greater the tendency towards shrinkage. In general more care should be used in the selection of the aggregate so that the desired workability can be obtained with a mix not richer than 1 part cement to 3 parts of aggregate.

One source of trouble in stucco work often overlooked is variation in subsequent batches caused by inaccuracy in measuring. Bulking of sand due to moisture is probably the biggest source of error. Very few plasterers take into account that sand

*F. O. Anderegg writes: In the course of studies recently made by the writer with others, the results of which are not yet available in published form, there are being developed two mathematical equations for grading aggregates with results to determine the tolerance limits of grading. In connection with these studies it appears that a limit of 35% material passing the 100 mesh sieve (present American Concrete Institute Specifications) is too low. It appears that this 35% limit was fixed as a means of controlling the amount of very fine admixtures added to improve workability, and which are known to be harmful to the stucco. Most of this harm arises from the increased water requirement indicating that a more logical method of control might be to limit the mixing water to 2.5 or 2.75 gallons per hundred pounds of ready mixed stucco.

may bulk as much as 30%. It is recommended that sand for undercoat work be either kept uniformly wet or thoroughly dry.

Discussion—Where a mix of 1 part of cement to 3 parts of sand is recommended for undercoat work it is intended that the sand be proportioned on the basis of dry and rodded volume.

Workability is an important consideration in stucco mixtures. If a mix is harsh more time and effort are required for its application and in addition wastage will be excessive. Lime is the most commonly used plasticizing admixture to improve workability. In general the quality of stucco mixtures is improved by using the least amount of fine material consistent with necessary workability.

Hair or fibre is used only in the first coat of stucco in back plastered construction.

In properly proportioned and applied stucco it does not appear to be necessary to use waterproofing materials to increase the density of the slab. It is particularly important where water repellant waterproofings are used that the stucco coats be kept wet until they have had sufficient time to properly cure. If they dry out too rapidly the moisture that is essential to curing cannot re-enter.

Discussion—The use of waterproofing in stucco mixes is the source of more discussion than any other factor connected with stucco. Opinions vary widely regarding the necessity or advantages of waterproofing. Even among those who insist that waterproofing is advantageous there is a wide difference of opinion regarding the usefulness of the different kinds. Test data available are not sufficient to warrant any other conclusion than that we must rely on properly applied and properly cured stucco to develop satisfactory results.

In view of the wide difference of opinion and the claim that integral waterproofing of a repellant nature is advantageous in reducing efflorescence and discoloration the Committee feels that this subject should be investigated thoroughly before any change is made in its present recommendations.

The introduction of color in stucco requires very accurate control in the preparation of finish coat material. The development of modern textures also requires considerably more plasticity in portland cement mortars than was needed for rough cast coats or float finishes of the past decade. Demand for plasticity has led to the use of numerous plasticizing agents in finish coat stucco without full knowledge of the effect upon the material. In view of the severe exposure which stucco must withstand only mortars of the highest quality should be used. In order to insure

high quality, finish coat portland cement stucco should be required to meet the Tentative Standard Specifications adopted by the American Concrete Institute in February, 1929. Especially where color is to be used, factory prepared finish coat is recommended provided it meets standard specifications.

Discussion—The trend toward textures in finish coat stucco has increased very greatly during the past 6 to 8 years. Mixtures that were quite satisfactory prior to this time cannot be used for modern textures. The result is that the use of plasticizing agents has increased very rapidly. The following are commonly used:

Hydrated lime
Asbestos flour or fibre
Clays
Pulverized marble or silica
Diatomaceous earth

The use of plasticizing agents in general has increased the total amount of fine material in finish coat stucco over that which is used in base coats. There is disagreement as to whether the increase in the percentages of admixtures leads to unsatisfactory results. One group claims that finish coat material is merely a decorative and color coat and that if the under-coat work is properly done the finish coat does not need to be of high quality mortar from the standpoint of strength and density. The other group claims that the finished coat material being exposed immediately to the action of frost, acids in the air, efflorescence and absorption of dirt from the atmosphere should be composed of a strong dense mortar. No direct data are available to support either of these contentions and experience in certain sections seems to bear out both. More information is needed on the question. The Committee holds to the point that a portland cement stucco should have the properties of a portland cement mortar and, therefore, recommends that the finish coat material have essentially the same requirements as the base and should meet the Tentative Specifications of the American Concrete Institute for Finish Coat Stucco.

Discussion—Opinions also differ widely on the effect of rich mixes in portland cement finish coat stucco on shrinkage. It is contended that a mortar of 2,000 pounds per sq. in. contains sufficient cement to cause excessive shrinkage cracks and that if a weaker mortar were used the cracking would be less harmful. The other contention is that a certain degree of plasticity must be obtained in finish coat material regardless of how it is gotten and that it is no more harm-

ful to use a strong mortar in which there is a relatively large amount of cement than it is to get the plasticity through the use of admixtures. In other words, more information is needed on volume change in stucco mortars when applied to absorptive backings.

Number of Coats—Three coats of stucco are required on frame structures and on masonry. One or two coats are sufficient on monolithic concrete depending on the texture desired.

Application—The first coat should entirely cover and bond firmly to the base, since it attaches the stucco to the wall and sustains the weight of the other coats. It should be approximately $\frac{3}{8}$" thick over the face of the base in order to receive rough and deep scoring which provides mechanical key for the second coat.

In general first coat of stucco should be dashed on monolithic concrete and should be allowed to harden before it is touched in any way. Trowelling frequently entraps a considerable amount of air between plaster coat and concrete. An ordinary dash brush is used and a mortar of creamy consistency thrown on with a strong whipping action at right angles to the surface of the wall covering at least 75% of the wall surface. The mortar is composed of 1 part cement and $1\frac{1}{2}$ parts aggregate.

The function of the second coat is to straighten the wall and should be approximately $\frac{3}{8}$" thick. After it has stiffened it should be smoothed and compacted with a wooden float which will leave the surface rough enough to receive the finish coat.

Discussion—It is contended by some that the brown coat which is frequently finished with the steel trowel should be lightly cross scratched in order to provide sufficient bond for finish coat. This cross scratch may be deep enough to interfere with thin finishes. However, unless the brown coat is finished with a wooden float after the mortar has stiffened considerably it will probably be safer to lightly cross scratch the surface.

The finished coat is of the thickness required by the texture.

It is the Committee's recommendations that after each coat of stucco is applied a period of damp curing, at least 2 days, should be provided in order to let the cement in the mortar get a good start toward hydration and that the coat then be allowed to dry for several days before the succeeding coat is applied. Just prior to applying the succeeding coat the wall should be lightly and uniformly dampened to control suction but it should not be saturated. By allowing each of the first 2 coats to dry thoroughly for at least 5 days after they have been damp cured the shrinkage

due to evaporation of moisture will develop all cracks that are likely to occur in under-coats. The finish coat being generally thin, has the large part of its water rapidly absorbed by the second coat, consequently the small cracks that might develop immediately are compacted by the plasterer in the application of the texture.

Discussion—Whether considerable time should elapse between application of the various coats of stucco or whether they should be applied on succeeding days is a controversial question among stucco men. The Committee believes that the majority favor a curing and drying interval between courses but it recognizes that there is no unanimity of opinion on this point and recommends that further study be given to this matter.

In applying moisture for curing or regulating suction, a fine fog spray is recommended in preference to a strong hose stream. The walls should never be completely soaked with water as this will lead to efflorescence. For curing stucco coats, the fine spray should be applied frequently so that the wall does not become dry at any time during the first two days, but at no time should sufficient water be applied to the stucco to cause saturation.

No other phase of portland cement stucco work is so neglected as that of protection and curing. While curing is of vital importance in all forms of concrete, it is particularly important in thin stucco slabs that may be subjected to excessive absorption of water by the backing and to excessive evaporation from hot dry winds.

Readers are referred to the JOURNAL *for March, 1930 for discussion which may develop.*

Disintegration of Concrete

Report of Committee 803—Disintegration of Concrete

BY G. M. WILLIAMS,* AUTHOR-CHAIRMAN

To PROFESSOR WILLIAMS *was assigned the task of preparing a summary of available knowledge of the nature of "corrosion" as found in Concrete—its causes, effects and control in (1) manufacture, (2) curing, (3) insulation or protection. He has had the close cooperation and constructive criticism of the following, the members of Committee 803: John R. Baylis, Bureau of Engineering, Dept. of Public Works, Chicago; D. G. Miller, Senior Drainage Engineer, U. S. Dept. of Agriculture, University of Minnesota; T. Thorvaldson, Director of Chemical Research, University of Saskatchewan, each of whom approves the report as made here by the author-chairman. This was the first available report from the new committees organized last spring.*—EDITOR.

DURING the last thirty years portland cement concrete has become one of the most valuable of structural materials adaptable to an almost infinite number of purposes owing to the ease with which it may be molded into useful forms. It has not only taken the place of older materials but has perhaps a wider variety of uses than any one of the materials which it has supplanted. Years of experience with wood and stone and steel have established conditions under which they may be used with apparently no limit to their lives. Under other conditions sometimes encountered their lives may be extremely short unless some form of protection or treatment is afforded. It can be stated safely that no material of engineering is permanent under all possible conditions of use. Therefore it is to be expected that under

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some exposure conditions the useful life of concrete may be reduced to a fraction of that which is necessary for and expected of a permanent material. Deterioration of concrete under a few of these many new applications does not necessarily indicate that it is a material unsuited to such uses but rather that study must be made to determine causes and to discover possible means of alleviation and their application in practice. The most common forms of deterioration encountered may be classified under the headings of, (1) acid action, (2) weathering, (3) action of sea water and (4) action of alkali.

The life of concrete exposed to one or more of the foregoing conditions has in numerous cases been cut short, as measured by appearance and loss of strength brought about by chemical changes in the cement, to such an extent that doubts have been expressed as to the advisability of its use under such conditions of exposure. While much work remains to be done field and laboratory studies have furnished much information as to how such disintegrations occur and what precautions in the future will alleviate if not fully eliminate much of the rapid deterioration which has resulted under such exposures. Diagnosis of causes of deterioration and the prescription of suitable remedies especially in the early period of concrete destruction has been handicapped by lack of knowledge of the chemistry of cement. That the cement in the concrete has been altered chemically has been apparent in the earliest studies of these forms of disintegration, but little has been known concerning the reactions actually taking place. Studies of the constitution of cement and the combination of these constituents with substances such as salts in solution will be of assistance in explaining the changes which cement undergoes and conditions which must be provided for to insure greater permanency.

THE ACID DISINTEGRATION OF CONCRETE

It is well known that cement, both in the hydrated and unhydrated forms is soluble in many organic and inorganic acids. Most cases of acid disintegration of concrete structures have occurred in peat soils. Both in Europe and on this continent, building foundations and hydraulic structures of portland cement concrete exposed to ground waters draining through peat soils

have been attacked. In Europe Rennie, Volger, Tacke, Bersch and others have studied peat soils and the latter three have discussed the disintegration of portland cement concrete exposed to the soil acids. In America Alway[1] and Elliott[2] have reported on deterioration of cement under similar conditions. The Bureau of Standards[3] has reported a case of disintegration of the acid type, probably due to some organic soil acid, where peat was not present. Different investigators are not in agreement as to the causes of deterioration but the action is generally attributed either to (1) humic acids, (2) the oxidation of iron sulphides or (3) hydrogen sulphide, of which the first two are considered to be of most importance. In any case the visible effect is the dissolving away of the cement on exposed surfaces, freeing the aggregate particles which fall away in case the action is progressive. The practical conclusion readily apparent is that portland cement structures must be protected from contact with acid soils and waters if they are to be permanent.

THE WEATHERING OF CONCRETE

All structural materials exposed to alternate heat and cold and wetting and drying tend to disintegrate at a rate dependent upon their relative quality and the severity of exposure. Wood rots, or dries and cracks with separation of the wood fibers, iron rusts and rocks slowly decompose to form soil when exposed to changing climatic conditions. Concrete responds in the same manner as evidenced by observations of structures which have been in service from a few to many years. The hydration of cement which may extend over a long period of time liberates free lime which tends slowly to carbonize. Both forms are soluble in water (lime in pure water and calcium carbonate in water containing carbon dioxide) and may be removed if the concrete is permeable and exposed to moisture. Concrete as a structural material has been in use a comparatively short time so that it is not possible to state what the average life should be under the varying conditions of its use. However it would seem that enough is now known concerning cements, aggregates and processes of fabrication to justify the statement that the probable

[1]Alway—"Disintegration of Tile in Peat Soil" American Peat Society, Vol. 15, No. 3, July 1922.

[2]Elliott—"Effect of Organic Decomposition Products from High Vegetable Content Soils Upon Concrete Drain Tile" Journal of Agricultural Research, Vol. 24, No. 6, May 12, 1923.

life of good quality concrete under normal atmospheric conditions will be as great as for any competitive building material. Most cases of deterioration now at hand of concrete exposed to atmospheric conditions can be accounted for by disregard of standards of materials and practice in its manufacture which are now recognized as of fundamental importance.

DISINTEGRATION IN SEA WATER

During the latter part of the 19th century many studies and experiments were made by European engineers and chemists to determine the cause of disintegration of cement in sea water construction. Among the European investigators are found the familiar names of Candlot, Dyckeroff, LeChatelier, Maynard and Michaelis. In their studies portland, slag, natural and modified cements were used and various theories were advanced to explain the processes of disintegration. The work done by these men served as a starting point as well as a source of reference when studies of sea water and alkali water disintegrations were begun in America. With the increasing use of portland cement in sea water construction in America at the close of the last century the same types of disintegration appeared and many references to the trouble began to appear in American technical literature.

Probably the most extensive study in America was that made by Bates, Phillips and Wig[3] in which mortars and concretes of portland, iron ore, slag and natural cements employed in the laboratory and in sea water exposures. Their conclusions (1912) may be briefly summarized as follows:

1. Properly made portland cement concrete when totally immersed is apparently not subject to decomposition by the chemical action of sea water.

2. Natural, slag and other special cements tested in concrete mixtures showed normal increase in strength with age both in sea water and in fresh water.

3. In the form of neat briquettes most of the portland cements of high iron content, several of the cements of high or normal alumina content and one special slag cement did not show any marked difference in tensile strength whether exposed to fresh or sea water for all periods up to two years. Other cements of

[3]Bates, Phillips and Wig—"Action of the Salts in Alkali Water and Sea Water on Cements." Bureau of Standards Tech. Paper No. 12, 1912.

various compositions showed signs of disintegration after a few weeks.

4. All cements resisted disintegration in sea water better in mortar mixtures than in the form of neat briquettes. In most cases the mortar briquettes had normal strength up to 2 years exposure.

5. In the presence of sea water or similar sulphate-chloride solutions:

(a) The most soluble element of the cement is the lime. If the lime of the cement is carbonated it is practically insoluble.

(b) The quantity of alumina, iron or silica present in the cement does not affect its solubility.

(c) The magnesia present in the cement is practically inert.

(d) The quantity of SO_3 present in the cement up to 1.75 per cent does not affect its solubility but a variation in the quantity present may affect its stability by affecting its rate of hardening.

6. The change which takes place in sea water when brought into intimate contact with the cement is as follows:

(a) The magnesia is precipitated from the sea water in direct proportion to the solubility of the lime of the cement.

(b) The sulphates are the most active constituents of the sea water and are taken up by the cement. Their action is accelerated in the presence of chlorides. No definite sulphate compound was established.

(c) The quantity of chlorine and sodium taken up by the cement is so small that no statement can be made as to the existence of any definite chloride or sodium compound formed with the cement.

7. Metal reinforcement is not subject to corrosion if embedded to a depth of 2 inches or more from the surface of well made concrete.

In connection with conclusion No. 7 it should be noted that the specimens were immersed throughout the duration of the exposure and not subjected to alternate wetting or drying as is that portion of a reinforced structure in which most cases of corrosion of steel have been noted. As a measure of deterioration the increase in SO_3 and MgO content at various distances in from exposed surfaces was determined.

The results of a survey and inspection in 1916 and 1917 of

most of the concrete structures in sea water along the American Coasts together with many others in Canada, Cuba and Panama are reported by Wig and Ferguson.[4] They conclude that well made portland cement concrete properly placed, if not subjected to mechanical abrasion and erosion, is permanent in sea water. The foregoing refers to plain unreinforced concrete. On the contrary the majority of reinforced concrete structures subjected to sea water action, at the times of these inspections, were showing evidences of deterioration. Many instances of failure of plain concrete were found but these were generally attributed to the use of excess mixing water, poor aggregates and lack of protection of the carbonized surface skin of the concrete. They concluded that the deterioration of plain concrete may be due to several causes but that the underlying one which is chemical disintegration cannot take place unless the original surface is first abraded or eroded by mechanical means. However since all concrete is permeable to some degree and chemical studies have shown increase in sulphate content of the mass at and near the surface it would seem that there must always be reaction with the constituents of the cement especially the lime, tending to lower the strength although these changes may occur so slowly that the useful life of such a structure may not be materially reduced. Prevention of corrosion of embedded steel is dependent upon permeability and absorption of the concrete and depth of embedment and this inspection indicated that under some conditions a 3-inch embedment was not sufficient.

DISINTEGRATION IN ALKALI SOILS AND WATERS

In some localities, especially in the arid and semi-arid regions of Western United States and Canada, soluble salts commonly referred to as "Alkali" are found in the soil and ground water. What is known as "white alkali" is usually a mixture of the sulphates and chlorides of sodium, calcium and magnesium, while "black alkali" so called because of its tendency to dissolve vegetation or organic matter and stain the surface of the soil a brown or black color, contains a large percentage of sodium carbonate together with smaller amounts of the white alkali.

[4]Wig and Ferguson—"What is the Trouble with Concrete in Sea Water." Eng. News-Record, Sept. 1917.

The alkali action on cement is generally due to the sulphates of sodium, magnesium or calcium present in water solutions.

The disintegration of portland cement concrete in alkali soils and waters has received the attention of engineers and chemists on this continent during the past twenty-five years, following the development of irrigation in the Western States. Headden[5] of Colorado and Tannatt and Burke,[6] of Montana, in 1908 described the disintegration of concrete by alkali salts in the soil and ground water, the former with reference to failures of cement drain tile and the latter in connection with disintegration of cement mortar and clay brick in the sewers of Great Falls, Montana. Soon after, Jewett[7] described the condition of concrete irrigation structures of the U. S. Reclamation Service which were exposed to alkali ground waters and pointed out the apparent similarity between this so called alkali disintegration and that found in sea water.

Tannatt and Burke concluded that "the action upon the cement was a chemical action, that the destructive agent came from the outside of the sewer and that the disintegration of the cement cannot be charged to any action arising from the sewage or gases from same." In a later report they stated: "The disintegration of cement by alkali salts is principally due to reaction between these salts and the calcium hydroxide necessarily present in set cement. As a result of these reactions relatively insoluble new compounds are formed in the body of the cement structure. These new compounds have greater weight and require greater space than the Ca(OH) replaced. New compounds force apart the particles of cement, thus weakening or breaking the binding material." The Bureau of Standards in a report[3] previously referred to stated that a hydraulic cement can be readily decomposed if intimately exposed to the chemical action of various sulphate and chloride solutions.

While these studies seem to show conclusively that disintegration of concrete by alkali waters is due primarily to chemical reactions between the cement and salts in solution many engineers believed that the disintegration was physical, rather than chem-

[5]Headden—"Destruction of Concrete by Alkali." Colorado Agr. Exp. Station, Bul. 132.

[6]Tannatt and Burke—"The Effect of Alkali on Portland Cement." Montana Agr. Exper. Sta. Bul. 69.

[7]Jewett—Proceedings A. S. T. M. 1908.

ical, due to crystallization of salt in the pores of the concrete and that this action was made possible by concrete of poor quality, permeable and absorptive. To determine the effect of salts on concrete of known quality the Bureau of Standards undertook an investigation[8] in 1913 which involved the manufacture of eleven carloads of cement drain tile comprising sixteen varieties or types and their installation in working drains in eleven localities, eight of which were in the irrigated districts of the west where the ground waters varied considerably in concentration and constituents, with the sulphate predominating in most cases. Later a large number of concrete blocks were molded and placed in sulphate waters, usually adjacent to concrete structures which had been affected by salts. Inspections and tests of the block and tile from each drain at intervals of a few years led to the following conclusions[8] in 1919.

1. Extent and rapidity of disintegration in sulphate waters depends upon concentration of salts in waters to which the concrete is exposed.

2. In concrete blocks containing reinforcing rods disintegration appears to be aided and accelerated in some cases by corrosion of embedded steel and consequent cracking of the concrete as has been observed in some reinforced concrete structures exposed to sea water.

3. Structures placed in alkali soils or exposed to alkali seepage waters should be given all possible protection by drainage.

4. Seepage waters and alkali soil conditions may be encountered which will disintegrate portland cement concrete of the best quality

5. Alkali salts are not uniformly distributed throughout the soil or large bodies of seepage (ground) waters and it will be difficult to determine in advance the concentrations to which a structure may later be exposed.

6. For the same concentration of soluble salts and the same aggregates, resistance of mass concrete to alkali action appears to vary with the cement content or richness of the mix.

[8]Bureau of Standards Tech. Paper 214. See also Papers 44, 95 and 307.

7. Porous or permeable tile due to the use of lean mixtures or relatively dry consistencies are subject to disintegration in sulphate waters of relatively low concentrations.

8. Dense tile of the best quality, exposed to sulphate waters, are subject to disintegration depending upon concentrations of salt in seepage water.

9. Disintegration may be manifested in sulphate waters by physical disruption caused by expansion resulting from crystallization of salt in the pores, *but it is primarily due to chemical action between the salts in solution and the constituents of the cement.*

10. A thin carbonized outer skin at the surface is apparently unaffected but this coating is not impermeable so that salts may be carried through into the mass.

11. With other conditions equal tile of lowest permeability will be the most durable. There appears to be little relation between permeability and the related factors of porosity, absorption and density.

In an extensive laboratory investigation to establish chemical requirements and tests for concrete drain tile to be exposed to alkali soils and waters, Schlick[9] included tests of drain tile from the same lots employed in the Bureau of Standards field investigation. He found action to be generally most rapid in magnesium sulphate, followed by sodium sulphate, with little deterioration apparent in chloride and carbonate solutions.

In 1918 at a General Meeting of the Engineering Institute of Canada held in Saskatoon, a group of papers[10] were presented describing disintegration of concrete building foundations in Manitoba and Saskatchewan and of irrigation structures in Alberta. In 1918 the Calgary Branch of the Engineering Institute began a field investigation[11] by exposing concrete blocks of known quality to sulphate waters. In 1919 a similar field investigation[12] was started by MacKenzie at the University of Saskatchewan. Concrete blocks of different qualities were placed in sulphate ground waters at a depth of 6 to 8 feet below the ground surface,

[9]Schlick—"The Action of Alkali Salts on Concrete Drain Tile." Bul. No. 89, Iowa State College, 1928.

[10]Journal Engineering Institute of Canada, Aug. and Sept., 1918.

[11]Dawson—Journal Engineering Institute of Canada, October, 1920.

[12]Mackenzie—Journal Engineering Institute of Canada, April 1920.

thereby eliminating the possibility of frost action. Analysis of soil waters showed great variation in sulphate cencentrations at points only a few feet apart with the result that a good quality concrete was disintegrated while a poorer quality exposed to lower concentrations were apparently unaffected.

The foregoing field investigations in the United States and Canada during the period from 1913 to 1921 led to concordant conclusions which confirmed the results of earlier laboratory tests that disintegration was a chemical action and that high quality portland cement concrete could be disintegrated when exposed to sulphate waters.

In 1921 a Committee on Deterioration of Concrete in Alkali Soils was appointed by the Engineering Institute of Canada to continue the study of the alkali-concrete problem. This investigation was financed by the three Prairie Provinces, interested corporations and the National Research Council of Canada, the latter furnishing the greater portion of the funds, and a total of approximately $50,000 was expended up to 1928, after which date the research was taken over by the National Research Council of Canada and continued at the University of Saskatchewan. Of this amount about $42,000 has been devoted to research in the chemical laboratory under the direction and supervision of T. Thorvaldson, head of the Chemistry Department of the University of Saskatchewan.

During the summer of 1921 a co-operative investigation involving both laboratory and field studies was started at University Farm, St. Paul, Minn., by the Department of Agriculture, University of Minnesota, The Minnesota State Department of Drainage and Waters and the Bureau of Public Roads of the U. S. Department of Agriculture, the work being directed by Dalton G. Miller. This investigation like the one inaugurated by the Engineering Institute of Canada is still underway. These two independent investigations have done much to advance the available knowledge of what takes place when portland cements are brought into contact with alkali salts in solution and their conclusions have been in close accord so far as their efforts have been parallel. The published conclusions of these two investigations to date are briefly summarized below.

Conclusions[13] drawn by T. Thorvaldson at the University of Saskatchewan.

1. The first reaction of sodium sulphate solutions when brought in contact with hydrated cement is to speed up the natural process of hydration of cement with liberation of lime, followed by rapid disintegration. The action of magnesium sulphate differs in that magnesium hydroxide is precipitated and the liquid remains nearly neutral, thus producing ideal conditions for the hydrolysis of the cement.

2. In the mixtures of the two sulphate solutions (sodium and magnesium) the magnesium controls so long as it is present, after which the sodium takes part.

3. Complete disintegration may take place without any disruption of mass due to crystallization. In the case of a structure exposed to alternate wetting and drying, crystal formation accompanied by frost action may be the final cause of disintegration.

4. Mortar specimens made from different portland cements of equal quality as measured by physical tests do not necessarily show equal resistance to sulphates.

5. Mortars made with pure tricalcium silicate ($3\ CaO\ .\ SiO_2$) and with pure beta-dicalcium silicate ($2CaO\ .\ SiO_2$) are not disintegrated in sodium sulphate but are disintegrated in magnesium sulphate.

6. Mortars made with these two silicates to which tricalcium aluminate ($3\ CaO\ .\ Al_2O_3$) is added are disintegrated rapidly in both sodium and magnesium sulphate solutions.

7. A mortar made with a cement composed of 21.5% tricalcium aluminate, 52.7 tricalcium silicate and 25.8 beta-dicalcium silicate which had the same strength as a mortar of normal

[13]Shelton—"Action of Sodium and Magnesium Sulphates on Constituents of Portland Cement." Ind. & Eng. Chemistry, Vol. 17, No. 6, June, 1925.

Thorvaldson, Harris and Wolochow—"Disintegration of Portland Cement in Sulphate Waters." Ind. and Eng. Chemistry, Vol. 17, No. 5, May 1925.

Thorvaldson, Vigfusson and Larmour—"The Action of Sulphates on the Components of Portland Cement." Trans. Royal Society of Canada, Vol. XXX, Sec. III, 1927.

Thorvaldson, Larmour and Vigfusson—"Expansion of Portland Cement Mortar Bars During Disintegration in Sulphate Waters." Engin. Journal, Canada, April 1927.

Thorvaldson and Vigfusson—"Effect of Steam Treatment of Portland Cements Mortars on Their Resistance to Sulphate Action." Journal E. I. C., March 1928.

Thorvaldson and Grace—"The Hydration of Aluminates of Calcium. 1. A New Crystalline Form of Hydrated Tricalcium Aluminate." Canadian Journal of Research, May 1929.

Thorvaldson and Shelton—"Steam Curing of Portland Cement Mortars. A New Crystalline Substance." Canadian Journal of Research, July 1929.

Thorvaldson—"Notes on the Relative Resistance of Various Cements to the Action of Sulphate Waters."

portland cement behaves like mortars from the normal cement when exposed to sulphate solutions.

8. Steam treatment of mortars (above 100° C.) which normally are disintegrated in both sulphate solutions causes enormous increase in resistance in sodium sulphate and greatly retards the disintegration in magnesium sulphate.

9. Steam treatment speeds up the hydration of the silicates in the cement, thus causing increase in compressive strength. The increased resistance to sulphates is however not primarily due to the increase in strength but to other chemical changes which take place at the same time. These are the formation of a lower and more stable hydrate of tricalcium aluminate ($3CaO.Al_2O_3.6H_2O$) and the combination of the highly reactive free lime in the hydrated cement with silica. Both of these products are stable in solutions of sodium and calcium sulphate and fairly resistant to the action of solutions of magnesium sulphate.

10. Different portland cements (products of different mills) have different rates of disintegration when exposed to the two sulphates. Thus cement No. 1 may disintegrate faster than cement No. 2 in solutions of sodium sulphate while the rate of disintegration in solutions of magnesium sulphate is in reverse order. Likewise one cement may disintegrate more rapidly in dilute solutions and more slowly in concentrated solutions, while a second may react in the reverse order.

11. A study of high alumina cements indicates that as a class they are more resistant to sulphate action than portland cements, but that the variation in sulphate resistance between different brands of high alumina cement is found to be greater than the variation between different brands of portland cement. The best high alumina cements tested had high resistance to magnesium sulphate but lean mortars slowly disintegrated in sodium sulphate solutions while richer mixtures show no appreciable action in the course of years. The alumina cements disintegrate more rapidly in ferrous sulphate than in sodium or magnesium sulphates while they are readily attacked by solutions of sodium carbonate (black alkali) and sodium phosphate.

12. Results of mortar tests of slag and natural cements indicate them to vary from low natural resistance to a resistance much

higher than that of the best portland cement. This is especially the case when comparing the resistance to solutions of sodium sulphate; the resistance to solutions of magnesium sulphate is usually much lower. It is pointed out however that these cements furnish mortars and concretes of much lower compressive strength than portland cements so that the combined effect of sulphate and frost action may be much more severe than in the case of portland cements of considerably lower natural resistances.

13. Neat cements may fail more rapidly than rich mortars or concretes made of the same cement when exposed to the same conditions.

Conclusions[14] drawn by Dalton G. Miller at University Farm St. Paul, Minnesota.

1. Standard portland cements vary greatly in resistance to sulphate waters; under the same exposure conditions the more resistant cements have outlived those of less resistance by as much as eight times.

2. Portland cements that have failed quickly in the laboratory in solutions of sodium sulphate have ordinarily displayed low resistance in the field to the action of mixed salts.

3. The standard physical tests and chemical analyses of portland cements give no indication of resistance to sulphate waters.

4. The resistance to disintegration of a cement may be greatly increased by curing in steam at a temperature of 212° F. and upward.

5. Resistance to sulphate action can be increased by permitting concrete to dry and harden in air after the normal wet curing period is completed. A short curing period in water followed by a long period of drying in air before exposure to

[14]Miller—"Laboratory Investigations of the Influence of Curing Conditions and Various Admixtures on the Life of Concrete Stored in Sulphate Solutions as Indicated by Physical Changes." Proceedings A. S. T. M., Vol. 24, 1924.
Miller—"Volume Change as a Measure of Alkali Action." Public Roads, July 1924.
Miller—"The Action of Sulphate Waters on Concrete." Public Roads, Oct. 1925, also Nov. 1927.
Miller—"Four Important Factors in the Manufacture of Concrete Pipe." Trans. Am. Soc. of Agr. Engrs., Vol. 20, 1926.
Miller—"Resistance of Portland Cement Concrete to the Action of Sulphate Waters as Influenced by the Cement." Proceedings A. S. T. M. Vol. 28, 1928.
Miller—"High Alumina Cements and Sulphate Waters." Bulletin of the Minnesota Federation of Architectural and Engineering Societies. June 1926.
Miller—"Action of Alkali Salts on Portland Cement Mortars." Engineering and Contracting, April 12, 1922.

alkali water is better than a long curing period in water and immediate immersion in salt solutions.

Perhaps to most engineers the most important conclusions to be drawn from these two investigations are:

1. The products of different cement mills vary greatly in resistance to sulphate waters when exposed to similar conditions.

2. Steam curing of concrete, where practicable, will greatly increase the life of structures exposed to sulphate solutions and in the case of sodium sulphate waters may insure permanency.

A further study of the effect of alkali salts on cement is reported by Burke.[15] He reports that magnesium sulphate is more active and destructive than sodium sulphate and states that solutions reacting with cement which tend to increase its weight and volume destroy concrete samples rapidly with solutions that tend to decrease its relative weight and volume show little or no tendency to destroy concrete samples. He also finds that carbonation of the lime liberated by hydration renders concrete more resistant to the attack of alkali sulphates. Burke finds high alumina cement more readily attacked by magnesium than by sodium sulphate and predicts that its deterioration will be more rapid in magnesium sulphate; also that calcium silicates are more readily attacked and to a greater extent per unit of time than the aluminates; and finally disintegration is due first to chemical action and secondly to physical changes brought about as the result of such actions.

The results of another chemical laboratory investigation has been reported[16] by Baylis. He emphasizes the importance of impermeability in pointing out that when concrete is exposed to water or the weather calcium hydroxide is liberated and reacts with carbonic acid to form calcium carbonate, which in the presence of water corrosive to it dissolves slowly. The action tends to be retarded by the presence of gelatinous compounds of alumina and silica but freezing or surface friction tends to hasten corrosion by removal of the gelatinous compounds. As a measure of corrosion and as an indicator that surface protection by waterproofing should be afforded Baylis proposes that the alkalinity of

[15]Burke—"The Chemical Action of Alkali on Hydraulic Cements." Bul. No. 74 Iowa State College 1925.

[16]Baylis—"Corrosion of Concrete." Trans. Am. Soc. C. E. 1927.

the concrete be determined in the mass near the surface. If the alkalinity at ¼″ from the surface is found to be less than 200 parts per million or at a depth of ½″ to ¼″ from the surface less than 1200 parts per million some surface protection must be applied to prevent disintegration.

The foregoing discussion gives a brief historical review of the studies made to determine the causes of concrete disintegration and the observations made and in some cases the method of treatment proposed has been outlined. Most engineers are not so much concerned with details of the reactions taking place when concrete disintegrates as they are with means of retarding or entirely preventing action on structures built or proposed in which portland cement as now constituted is to be used. Chemical studies must continue before the problem of concrete in alkali soils is solved but in the meantime the progress made to date will permit the use of concrete under certain conditions with greater assurance of long life than in the past.

THE PREPARATION OF CONCRETE TO BE EXPOSED TO ALKALI SALTS IN THE SOIL AND GROUND WATER

Observance of the following precautions in the selection of materials and in the preparation and curing will tend to result in a concrete of highest resistance to sulphate action.

1. Select a portland cement which has a high natural resistance as measured by preliminary tests.

2. Select a sound, durable well graded aggregate combined to result in the highest weight per cubic foot.

3. Resistance varies with cement content up to mixtures approaching neat cement; therefore use a rich mix.

4. Use as little mixing water as will result in a plastic mushy consistency preferably with a slump not greater than 3 in. to 5 in. depending upon the conditions of the work. Place concrete in the dry and remove excess water or laitance which tends to collect as deep masses are built up rapidly. Reduction in water content of successive batches under such conditions *to prevent formation* of excess water or laitance is to be preferred.

5. For large structures, cast in place, cure concrete under moist conditions for as long a period as possible and allow the

concrete mass to dry and harden in air before allowing alkali ground water to come into contact.

7. Concrete products and precast structural members should be cured in steam *above* 100° C. Lower temperatures will be injurious.

8. Backfill portions below ground level with gravel or crushed stone and provide drains outside and below the lowest portion of the structure wherever practicable.

9. Where thorough drainage cannot be obtained place bituminous membrane waterproofing continuously below and up the sides of footings and continue the waterproofing to the ground line on the outside. Bituminous paint coats cannot be considered efficient waterproofing.

10. Observing the foregoing precautions as to materials and mix for any given cement and aggregate (a) concrete of highest impermeability will probably be most resistant, and (b) generally the concrete of highest strength will be least permeable.

Readers are referred to the JOURNAL *for March, 1930, for discussion which may develop.*

Progress in Determining the Relation between Test Cylinders and Concrete in the Structure

BY HARLAN H. EDWARDS*

Results of tests in connection with the construction of four buildings for Scripps College, the second of a group of associated colleges to be built in Claremont, Calif., have been the means of improving materially the quality of the structures and reducing their cost. These tests, extending over a period of three years, together with others previously made on earlier structures form an interesting series, indicating the following conclusions:

(On structures where wood forms are used, provided normal spring or summer temperatures exist, and provided also that the structures are kept damp by frequent wettings for 21 days after placing concrete.) 1. Concrete is of a strength equal to or higher than that shown by test cylinders taken and cured in the laboratory under the standard A. S. T. M. specifications. 2. Loss of moisture from concrete soon after placing, through absorption into the wood forms and through percolation of excess clear water through cracks between boards, reduces the water-cement ratio at the time of set to produce higher strengths and a denser product. 3. A well-designed mix, based upon the fineness modulus theory, retains practically all its cement in the mass while clear water finds its way through joints between boards and runs away. This is not usually true on harsh mixes, however. 4. Cylinders cast in unwaxed cardboard molds surrounded by concrete in a section of wall form placed in a window or door opening and cured in the structure, when broken out for test in 28 days are reliable indicators of the character of the concrete then in the building. 5. Cylinders cured in damp sand on the job as per A. S. T. M. standards are frequently very erratic in test

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due to a low sand temperature unless controlled heating of the sand is in effect.

More than 300 six by twelve-inch cylinders have been tested to date in these investigations, certain phases of which will be continued on later buildings.

MATERIALS USED

Commercial 1-in. washed, screened granitic gravel passing a 1¼-in. round opening, having a fineness modulus of approximately 7.3 was used with washed sand having a fineness modulus of 3.4, both obtained from the Claremont plant of the Union Rock Co. Riverside cement was furnished by the Fox-Woodsum Co. of Claremont, while all cement and cylinders were tested by the Raymond G. Osborne Laboratories of Los Angeles. Cylinders were made by the writer, with an average maximum variation of approximately 5% with 7.8% as high and 1.6% as low.

PRELIMINARY TESTS

On the first structure, test records were kept of all concrete placed, the job being run similar to most good commercial work. The mix as is usual, was specified as a 1:2½:3½ field mix. Since the sand used bulked considerably in the damp state, this was really equivalent to about a 1:2:3.4 dry rodded mix, which, due also to the coarse sand, was harsh working and produced many rock pockets in spite of efforts of the contractor to prevent them.

Placed at a 6 to 8-in. slump with no admixture the average standard 28 day test was 2267 lb. per sq. in. for the job. All test cylinders were sent to the laboratory for moist room curing the second or third day after making, so curing conditions were quite uniform.

From these tests and the complete records of the aggregates used, it was found that 2000-lb. concrete by proper design could be obtained using a leaner mix, while at the same time obtaining ample strength and workability. In the second structure (1928) therefore, the standard cylinder average was 2168 lb. per sq. in. —less than 100 lb. difference, yet with 1 sack per cubic yard less cement in the mix which was a 1:4:4 field mix or a 1:6 real mix.

RELATION OF STRUCTURAL CONCRETE TO LABORATORY-CURED CYLINDERS

In 1929 work, tests were designed to determine the relation

of structural concrete to the standard laboratory-cured cylinders, but cool air temperatures made test results of concrete cured on the job so variable that further efforts were deferred until a recording thermometer became available to record the air and concrete temperatures during the curing period.

Certain tests were made, which shed valuable light upon this problem. Standard cylinders showed a uniform strength of from 2000 to 2150 lb. per sq. in. throughout the job. Tests numbered 23991 to 23993 by the laboratory were on 4-in. cubes cut from a 4-in. slab placed as a part of the second floor of the Recitation Hall over an opening which was later to be occupied by a dumb waiter shaft. The mix was 1:3.3:3.7 dry rodded or 1:6 real mix, 8-in. slump, with the surface of the slab floated to a monolithic finish. The average of the three cubes tested dry at 41 days was 3276 lb. per sq. in. or 2949 lb. per sq. in. after correction to the cylinder equivalent.

Another similar test of the same mix was placed as part of a fourth floor slab in Dormitory No. 3, cured as described using damp sand to retain the moisture on the slab surface, broken out during a change in design of that section of the structure, cut into 4-in. cubes and tested dry at 62 days. The average strength of two cubes was 3277 lb. per sq. in. the third being discarded due to the presence of a small rock pocket which reduced its strength test more than 15%.

Still another and equally as interesting a result is a section of 8-in wall of a similar mixture, placed in a door opening, cured there 24 days, sent to the laboratory for cutting into 6 x 6 x 12-in. prisms and tested dry at 28 days. Average air temperatures adjacent, from recording thermometer readings were 65° F., average concrete temperature 64½° F. by same means, with maximum and minimum air readings 90° F. and 46° F. The average 28-day test result of the three prisms was 2565 lb. per sq. in.

Generally speaking, it seems that the job strength of slab and beam concrete in normal temperatures is somewhat higher than wall concrete. The reasons for this are found in curing as well as placing operations. In curing, slab concrete can be kept wet continuously through the use of a covering of fine sand to retain the moisture. Walls, on the other hand, retain only such moisture

as is absorbed in each wetting, and lose this through evaporation, so unless by frequent wettings, walls are not allowed to dry out or whiten, moist curing conditions are not similar. A striking example of the results of insufficient watering on walls was shown in connection with the test on cubes from the fourth floor slab previously mentioned. A 6-in. interior filler wall beneath a stair was concreted of the same mix and in continuous pour with the slab and broken out at the same time. Six-inch cubes of this material tested 1601 lb. per sq. in. average as contrasted with the 3277 lb. average for the slab. This was accounted for by the fact that the thin wall having less volume than the 8-in. walls dried faster, missed many wettings as the laborer went around the outside of the building with his hose and was largely protected from interior watering by the stair.

EVIDENCES OF LOSS OF WATER AFTER PLACING

In every run of concrete it had been observed that in one hour's time the concrete stiffened considerably, yet according to cement test reports initial set did not take place for nearly three hours from the time of placing. In 4-in. slabs, men at the time of placing sank into them nearly the entire slab depth, while after an hour had elapsed, they sank in less than an inch. Concrete in walls at the time of placing could be rodded easily, while later it was im possible to work them at all. In a 9-ft. wall a noticeable settlement took place within the wall forms and through all form joints clear water in small quantities dripped to the floors below. The slump test showed that a 6 to 8-in. slump concrete had stiffened to a 2-in. slump material an hour later. This apparent stiffening of the concrete seemed to be due to the removal of excess water by three agencies—1st, cracks between form boards allowing water to drip away; 2nd, the forms themselves absorbing quite a little water; and 3rd, finishing operations on the slab, through the vibration of placing and working the concrete as well as leveling off the surface and troweling with added cement where a monolithic finish coat was planned.

Test series were therefore planned and made, to determine the effect of such loss of moisture on the concrete during this hour period with the result that an average increase in strength of 20% was shown, with a maximum variation of cylinders either way of

8%. All these tests were on 8-in. walls and 4-in. slabs. Added tests were made on laboratory-cured cylinders of the same batches curing three weeks damp and allowing them one week to dry out in the laboratory air, to approximate job concrete when dried after curing operations had ceased. These are shown in the last column of the table.

28-Day Tests—1928 and 1929

Cylinder No.	Real Mix	Initial Slump Inches	Slump 1 Hour Later	Strength Standard Lb. per sq. in.	Strength 1 Hour Later	Strength Dry
138	1:6	2¾	....	2806	....	....
139	"	"	....	2893	....	....
140	"	"	....	2604	....	....
149	"	"	1¼	....	3100	....
150	"	"	"	....	3065	....
151	"	"	"	....	3154	....
141	"	"	....	....	....	3106
142	"	"	....	....	....	3254
143	"	"	....	....	....	3024
152	"	"	1¼	....	....	4046
153	"	"	"	....	....	4377
154	"	"	"	....	....	3748
159	1:6.3	8	....	1984	....	....
160	"	"	....	2091	....	....
161	"	"	....	1946	....	....
162	"	"	....	....	....	2558
163	"	"	....	....	....	2665
167	"	"	1¾	....	2387	....
168	"	"	"	....	2378	....
169	"	"	"	....	2512	....
170	"	"	"	....	....	2905
171	"	"	"	....	....	2946
172	"	"	"	....	....	2856
226	1:6.1	8	....	2102	....	....
227	"	"	....	2159	....	....
228	"	"	....	2167	....	....
229	"	"	2–3	....	2476	....
230	"	"	"	....	2509	....
231	"	"	"	....	2502	....
314	1:6.1	6	....	2200	....	....
315	"	"	....	2269	....	....
316	"	"	....	2407	....	....
319	"	"	1	....	2824	....
320	"	"	"	....	2734	....
321	"	"	"	....	2758	....

CYLINDERS CAST IN WALL FORM

It was then determined that efforts should be made to learn the strength in the structure at 28 days. Since waxed cardboard

molds would not permit the penetration of water and the consequent equalization of water content in the concrete inside and outside of the mold, unwaxed cardboard cylinder molds were then secured in the hope that such equalization might more nearly be accomplished. Concrete as it was placed was then obtained through an opening made in the form, and run into metal pans for use in making the test. It was then rodded into the molds in the standard way, the specimens placed between forms in a section of window or door bulkheaded off for the purpose, and additional concrete was placed so as to completely surround them. Tops of the cylinders were separated from the enclosing mass by sheets of heavy paper, and the entire block of concrete was cured with the wall. Standard cylinders "as placed" were taken from the same concrete and cured in the laboratory as a check on quality. At about 25 days the cylinders were broken out, sent to the laboratory for capping and were tested in a semi-dry condition at 28 days. Some difference was expected due to variation in the curing temperatures as well as moisture content difference at the time of test. The following comparison, then, is of interest.

1928 Cylinders

Standard Test Average 3 Cylinders	Cast in Wall Form Average 3 Cylinders
2312	2018
2164	1850

In 1929 tests, it was planned to secure decisive test data on the relation between laboratory-cured specimens and cylinders cast and cured in wall sections. Therefore a number of cylinders were cast thus, always endeavoring to have 3 sets of 3 cylinders each on each directional exposure. The results of the first few groups were so erratic that further investigation was postponed until the recording thermometer previously mentioned could be obtained. The reason for this decision can be readily seen from the following record of cylinders all cast from the same batch of concrete but cured in an east and a north exposure within 15 feet of each other. Additional cylinders of the same batch were made and sent to the laboratory for moist curing and test, 3 being standard cylinders and 3 of concrete placed in a wood wall form, removed in 1 hour and cast in the cylinders.

Laboratory Cured		Job Cured	
Standard	1 Hour Later	East Exposure	North Exposure
2102	2476	1766	1446
2159	2509	1778	1398
2167	2502	1774	....

The recording thermometer was obtained too late to get any records of value on this year's work. 1930 work, however, will see several determinations of the temperature-strength relation. Concrete from one batch will be used to make 3 cylinders for laboratory curing to check quality; 3 taken from wood wall forms 1 hour after placing and sent to the laboratory for curing; 3 cast in unwaxed molds in a section of wall and cured with the structure, and a block of concrete 18 x 12 x 8 in. similarly cured from which 3 prisms 6 x 6 x 12 in. can be sawed for test. Temperatures within the wall will be obtained continuously from the time of placing by inserting the gas-filled bulb of the thermometer in a hole made for it by putting a tapered wood plug in the wall concrete between cylinders at time of casting, removing it when the concrete has stiffened. Air temperatures adjacent to each side of the wall will be obtained by a second bulb and another thermometer.

EFFECT OF CURING IN DAMP SAND ON JOB

Since temperature of curing is of importance in interpreting test results, these tests already mentioned were cured under standard 70° F. damp room conditions except where noted. This precaution was taken as the result of experiences on previous work where cylinders were cured on the job in damp sand as required by the A. S. T. M. specification C 31-21. Unaccountably low results were being reported by the laboratory on routine cylinders, so every possible source of trouble was checked without avail. Finally a set of cylinders was made, half of which were cured on the job in damp sand, while the other half went to the laboratory and were cured approximately under standard conditions. The average daily temperature of the sand was taken and the results solved our problem. They were:

7 days		28 days	
Damp Sand	Laboratory	Damp Sand	Laboratory
47°	68°	47°	68°
905	1338	2100	2635
766	1064	1582	2138

Tested by Mr. Converse of the California Institute of Technology in Pasadena, California.

Although days were warm under the Southern California sun, the damp sand retained the cold of the nights by evaporation of water during the day. This was not true in the case of the structure. While rapid evaporation of water from the damp sand, and the shade of a tree kept the day temperature of the sand from rising appreciably, the walls of the structure received heat from the warm air on all sides as well as from the direct rays of the sun, all of which far exceeded the slight cooling effect of evaporation on the mass of concrete. It was therefore plainly evident that in places where day and night temperatures were not very much alike, large errors could creep into an otherwise carefully controlled test, giving a final result which was misleading and incorrect.

LENGTH OF CURING PERIOD VS. JOB STRENGTH

Particular attention was given to the curing of the Scripps College structures to the end that maximum strength be developed from the material used. Early in the progress of the work, tests were made of cylinders cast in a wall section and wet down for a week as is usually specified and done. The wall was then left to the weather, which was very nearly at the normal 70° point, and cylinders were broken out in 28 days for test. The resultant average strength was 1103 lb. per sq. in. (av. of 1128, 1112, 1069) as compared to the laboratory-cured quality cylinders of 2164 lb. per sq. in. damp (av. of 2159, 2168). This thoroughly verified computations and led to the requirement that on all work concrete was to be kept *damp* by repeated wettings for a period of 21 days the frequency of wetting to be dependent upon weather conditions. This period was a minimum, increased as necessary to correct slow curing conditions in cold weather. The added cost of a laborer or two for this additional period over usual custom was very small when compared with the value to the completed structure of the increased strength obtained.

Readers are referred to the JOURNAL *for March, 1930, for discussion which may develop.*

VARIATIONS IN STANDARD PORTLAND CEMENTS

Report of Committee 202

BY P. H. BATES,* AUTHOR-CHAIRMAN

*This report is the work of P. H. Bates. Immediately on its completion his absence in Europe prevented consideration of comment and discussion by the critic members of Committee 202. Thaddeus Merriman, Chief Engineer, Board of Water Supply, New York City, one of the committee's members, very promptly prepared discussion which appears with the original report in these pages. R. E. Davis, Professor of Civil Engineering, University of California and G. M. Williams, Professor of Civil Engineering, University of Saskatchewan, members of the committee, have discussion under consideration. Prof. T. Thorvaldson, Director of Chemical Research, University of Saskatchewan, is prevented from giving immediate attention to the report by his absence in Europe on sabbatic leave * * * It may be recorded in this connection that other special committee assignments are being handled by the Institute in this way—selecting an author-chairman with great care to prepare a report and giving to the membership of the Institute his untrammeled and unrevised work coupled with the discussion of the members of the committee group. In this way, and especially with reports of certain pioneering characteristics, it is felt that the whole subject matter has a spontaneity sometimes lacking in reports wrung by compromise from a group of diverse viewpoints * * * This report, tending as it does to subject the prime ingredient of concrete to closer scrutiny by the user with special problems, has been selected by the Program Committee for consideration at the 26th Annual Convention. Discussion, therefore, is especially invited.*—EDITOR.

*National Bureau of Standards, Washington, D. C.

THIS paper is a report of Committee 202 on the topic, "Variations in Standard Portland Cements." The topic and the various headings under which it is discussed were suggested by a special advisory committee to the Board of Direction, and approved by the latter. The chairman's handling of the matter in this manner in no way indicates his approval in the method of discussing the properties of portland cements as we have them now on the market but, rather, indicates his acquiescence in a procedure which it is believed will quite likely be satisfactory in bringing to the attention of many some of the ranges in values of certain physical properties, which may be encountered in investigating typical portland cements.

The sub-topics under discussion cover questions of much interest to all studying and intelligently trying to use cement and concrete, and many data should be available. But a search of the literature reveals that in general the data are extremely meager. In fact it would seem that in most studies of concrete cement was not considered to be one of the variables and seldom are any of the characteristics of the cement presented, other than it was a standard portland cement and met the requirements of the standard of the American Society for Testing Materials or other similar organizations. Indeed, even when strength is under investigation there has been a steady effort in many outstanding researches to obliterate any apparent effect of the use of different standard cements by using a mixture of a number of them. Under such conditions one is confronted with paucity of data, notwithstanding the need of many. It is believed that this report will have more value in emphasizing this lack and, to a considerable degree, the need of data, than in citing what is actually available under the several designated headings.

It is felt also that the discussion will dispel the erroneous idea that there is such a thing as a standard portland cement. It is true that all manufacturers of the commodity make an especial effort to have it pass a certain set of standard requirements, but in so doing it has resulted that not only does the product of the majority of mills meet these at all times but the product may exceed these requirements to various degrees at any time. It is further believed that this discussion may serve to indicate that

portland cement does develop other properties than those of hardening and acquiring strength. It is hoped that it will be made clear that some properties, as volume changes and heat developed during the reaction with water, may be so paramount in special cases as practically to force the ignoring of strength.

Finally it is believed that this discussion will have served its most useful purpose if the importance of certain properties and the meagerness of data covering them are so sufficiently impressed upon even a very few readers that they will originate an intensive study to fill up the outstanding gaps in our incomplete knowledge of cement.

VARIATIONS IN EARLY STRENGTHS

The interest in early strength is too recent to permit of there being many published data available. Three years ago few were making any tests of other than neat tensile briquettes at ages earlier than 7 days. Then the efforts of some portland cement manufacturers to manipulate the making of their product so that it might come into the class of the high alumina cements, so far as high early strength was concerned, led to the breaking of test specimens after aging two or three days. But in the great majority of cases such testing has been confined to the making and breaking of tensile briquettes so that essentially there are few data available.

Committee C-1 of the American Society for Testing Materials, however, at the 1928 meeting of the Society presented a report of work wherein a group of laboratories had carried out certain strength tests of 32 brands of cement obtained from warehouses scattered throughout the United States.[1] Forty-six laboratories reported the strengths at 3, 7 and 28 days, of standard sand briquettes made from these cements. The average of the strengths so reported is given in Table I. Two laboratories reported the strengths of 6 by 12 inch cylinders, made of a 1:2.4:3.6 concrete, at 3 days, and four other laboratories in addition to these two obtained the strengths of the same concrete at 7 and 28 days. The averages of these values, as well as the strength at one year, obtained by one of the laboratories, are given in Table II.

[1]Proc. Amer. Soc. for Testing Materials, Report of Committee C-1, Vol. 28, Part 1, pp. 232-306. (1928.)

TABLE I

TENSILE STRENGTH OF STANDARD SAND BRIQUETTES

Average in lbs. per sq. in. obtained by 46 laboratories using 32 brands.

Cement No.	3-Day Tests	7-Day Tests	28-Day Tests
1	275	350	445
2	240	330	440
3	210	260	375
4	190	260	370
5	250	315	395
6	230	310	400
7	230	310	405
8	205	285	405
9	195	290	380
10	195	255	375
11	210	295	390
12	235	305	390
13	255	330	430
14	205	285	400
15	215	290	385
16	205	270	375
17	220	290	385
18	185	260	375
19	185	260	375
20	160	235	360
21	255	325	405
22	255	325	410
23	220	285	390
24	260	335	405
25	205	270	390
26	180	265	375
27	230	290	380
28	170	230	345
29	245	325	420
30	195	265	365
31	210	275	380
32	200	265	375
Average value	215	290	390
High value	275	350	445
Low value	160	230	345

These tables require but little comment. They serve to show quite strikingly that the cements of the type now on the market do vary considerably in strength, whether tested at early or later ages, either as mortar briquettes or as concrete cylinders. They further show that these deviations in concrete strength are still very marked at periods as late as a year. It is true that this is not long when measured by such an infinite period as indicated by "permanency." On the other hand, strengths even at one year are in reality only a matter of some special interest and of no particular value. All structures must be in use in whole or in part

TABLE II

COMPRESSIVE STRENGTH OF 32 BRANDS OF PORTLAND CEMENT

Average compressive strengths, lbs. per sq. in.

Compression tests of 6 by 12-in. concrete cylinders.
Mix 1:2.4:3.6 by weight (5 lb. cement, 3 lb. water, 12 lb. sand, 18 lb. coarse aggregate per batch).
Three-day results are averages from two laboratories.
Seven- and 28-day results are averages from six laboratories.
One-year results are averages from one laboratory.

Cement No.	3-Day Tests	7-Day Tests	28-Day Tests	1-Year Tests
1	1610	2840	4000	5140
2	1270	2200	3500	6190
3	1150	1940	3200	5680
4	880	1490	2610	4540
5	1370	2360	3550	5220
6	1300	2200	3430	4810
7	1080	1900	3220	4910
8	1010	1690	3200	5240
9	880	1870	3090	4620
10	880	1570	2820	4290
11	1070	2000	3240	4960
12	1160	1960	2960	5060
13	1340	2140	3700	5470
14	1060	1880	3270	5610
15	1170	1820	3290	4860
16	1090	1850	3140	4840
17	1270	2160	3660	5230
18	880	1490	2940	4640
19	1020	1670	2880	4950
20	820	1230	2360	4550
21	1460	2220	3400	4800
22	1470	2430	3880	4980
23	1180	1750	3040	5200
24	1240	2190	3390	4980
25	1040	1540	2850	5070
26	710	1220	2140	4070
27	1160	1740	2750	4360
28	680	1190	2370	5350
29	1180	1960	3260	4940
30	940	1610	2840	4830
31	1040	1530	2950	5230
32	920	1530	2870	5250
Average	1100	1850	3120	5000
High	1620	2780	4030	6190
Low	600	1070	2090	4070

so long before one year that the strength upon which they are built must have been developed long before that age. Further, one year is too short a period to furnish any indication of permanency in the great majority of cases. Hence the one year strengths can be of but little practical value.

The tables also show that the briquette is but little indicative of the strength which the cement may develop in a concrete. Thus, one cement which gave a briquette strength of 390 pounds at 28 days, gave a concrete strength of 2850 pounds per square inch at 28 days, while another cement which developed as a briquette 410 pounds per square inch gave a concrete strength of 3880 pounds per square inch. It is a fact that in the majority of cases there is a definite relation between early briquette strength and early concrete strength, as indicated by Fig. 3 of the Committee C-1 report. But this same figure shows the large number of exceptions. Further, one is not interested so much in the average strength of a group of cements as he is in those that deviate markedly from the average. To one contemplating the use of a cement the fact that 32 brands, in a certain kind of concrete, gave an average strength at 3 and 7 days of 1100 and 1850 pounds per square inch, respectively, has not nearly so much value as the fact that at 3 days one cement showed an average strength of 710 pounds per square inch and another 1610 pounds per square inch, while at 7 days one gave an average strength of 1190 pounds per square inch and another 2840 pounds per square inch.

Other interesting facts than the early strengths can be noted in these tables. Thus it can be seen that the cements testing lower at early ages show a greater gain in strength with age than do the higher testing ones. Cements 1 and 2 are of special interest in this respect. The latter gave a concrete strength at 3 days 25 per cent lower than the former, but at 1 year No. 2 had a greater strength than No. 1.

The interest in high early strength concrete is resulting in the rapid accumulation of data. However, the work of Committee C-1 which has been cited is so representative of commercial practice that it is hardly necessary to cite other data. Particular reference has not been made to any high early strength portland cements. This is due to the fact that several of the few now on the market are essentially not portland cements, according to the definition of the latter adopted by the American Society for Testing Materials and included in the United States Government Master Specification for Portland Cement, in that they do con-

tain additions, subsequent to calcination, other than water and calcined or uncalcined gypsum.

LATE STRENGTH

Not any data are cited under this heading. It is extremely infrequent that one can find data showing the strength of cement products at ages beyond five years. This is of course very early in the expected age of most structures and should essentially be considered an early age. If one, however, considers three or more years as late ages, then again one is confronted with the fact that cement has so seldom been considered a variable in the study of the cement product in question. However, in the section just presented in this paper and under the later topic of "Reaction to Curing Conditions" there are some data concerning such ages, where the cement has been a variable. Here there can be noted the fact that different cements will have different late strengths in the same cement product. This difference is just as prominent then as at the usual early testing periods. One can apparently obtain high or low strength in otherwise the same concrete at late ages by the choice of cement as readily as at early ages; or the choice of cement is as much the determining factor in the late strength of a concrete as is the proportioning or choice of the aggregates.

PERMEABILITY

Two of the latest investigations relating to permeability are those of Withey and Wiepking[2] and Collier.[3] Both used but one cement in their studies. In one case this cement was made in the middle west and in the other case on the Pacific Coast. But this fact does not enable one to draw any comparisons since about every other possible variable that could be introduced was present. Thus, one used stone and the other gravel; one used one type of specimen and the other another; the mixes were seldom proportioned alike; observations were made at different times and the results expressed differently. For the sake of illustrating the differences in test procedures, which are typical of those used by other investigators, and results, Table III is presented, giving

[2]Permeability tests on broken stone concrete: Withey and Wiepking, Bul. Univ. Wisconsin, Eng. Series IX, No. 2: Number 1245.
[3]Permeability of Concrete: Collier. Proc. Amer. Soc. for Testing Materials, Vol. 28, Part II, page 490.

excerpts from the published data of these two investigations. It is evident that it is not possible to determine if the two different cements produced any differences in the permeability.

TABLE III

EXCERPTS FROM DATA OF WITHEY AND COLLIER ON PERMEABILITY

Proportions by Weight						
Cement	Sand	Stone or Gravel	% H_2O	Fineness Modulus	"Average rate of leakage. Gal. per hour per sq. ft." between 40-50 hours.	Remarks
Withey						
1	1.56	3.32	8.3	6.13	.000101	"Leakage" measured by flow *into* the concrete.
1	2.56	4.44	7.9	5.98	.000241	
1	2.72	4.28	9.3	5.78	.000239	"The specimens of rich mixes . . . were so impervious that no leakage was apparent at the free surface."
Collier						
			w/c		"Flow, gal. per hour at end of 100 hours."	
1	1.66	3.32	0.7	5.41	.000071	Flow measured by water going into concrete; surface of the first and third concretes cited was dry at the end of the 100 hour test period; the surface of the second concrete was wet.
1	2.22	4.44	0.8	5.41	.0134	
1	2.21	4.42	0.9	5.41	.00026	

w/c = water-cement ratio.

But since it is known that different standard cements do have different times of set, different rates of hardening, different rates of developing strength, etc., all of which are due to the kind and amount of the reaction products of the water on the cement, it would seem logical to assume that these products might have some decided influence on the permeability. But it should not be necessary to make any assumptions. It is therefore suggested that those who are thinking of conducting permeability work should introduce cement as one of the variables in their studies.

PROPORTIONING AND WORKABILITY

The discussion under this topic will be restricted largely to workability. It is not quite clear why proportioning is here

coupled with workability, as the former might just as properly have been coupled with any of the other topics. The variables under consideration in this paper are the different normal or standard portland cements and how they may affect various properties of products made therefrom. Proportioning, other than the ratio of cement to total aggregate, is not germane to the subject. If the cements are different in the several enumerated properties, then undoubtedly the amount of cement used in the product will affect the property under consideration. The relative amounts of the different cements used in concrete would affect differently the strength, both early and late, the permeability, the shrinkage and the heat of setting, as well as workability.

At the present time the term "workability" is very much to the fore in discussions of cements and concretes. Since this term is used to describe that condition of mortars or concretes under which they can be readily worked into forms or around reinforcing without segregation, it can be appreciated that it is a matter of much concern. This is particularly true since it is now so thoroughly realized that attempts to secure this property through the agency of increased amounts of water result only in lower strengths and increased likelihood of segregation. Furthermore, the increased demand for high testing, so-called "plastic" mortars and the increased use of concrete prepared at central mixing plants and hauled considerable distances before placing, has still further emphasized the workable properties of such materials. Finally the matter is brought to a climax by sales propaganda featuring the properties of certain agents reputed to develop workability when added to mortars or concretes.

The concern shown in this question, however, is a proper one and users of cement products are vitally interested in workability. Most unfortunately there are no accepted methods for measuring this property. The measuring of the "slump" of a mass of plastic concrete according to American Society for Testing Materials methods is far too crude; the measuring of the flowing out of a plastic mass on a plate after dropping it a number of times through a certain height is an improvement but still is but a crude measure of the relative ease with which pieces of the large aggregate will flow over one another under relatively violent

movement, or the readiness with which the different sized particles will separate according to their size.

Several investigators of the workability of concrete have been working with several types of apparatus. Pearson and Hitchcock,[4] Smith and Conahey,[5] and Smith,[6] have devised methods based upon the measurement of the penetration of one or more steel rods into a cylinder filled with plastic concrete under the action of certain forces. Smith and Conahey have also designed an apparatus described in the paper referred to in which the force required to deform a flexible cylinder filled with concrete is measured. Purrington and Loring[7] have used a concrete mixer in which the power required to operate it when filled with different concretes is measured. However, none of these has considered how much different makes of cement would affect their results; neither is it possible to correlate their results so as to determine if the cement has been a factor.

The investigations dealing with the relative workability of different cements have been confined to a study of this quality as developed by neat cement pastes. The earliest efforts were directed more towards measuring what is referred to as "consistency,"[8] and as a result the well-known Vicat needle was developed. The use of this indicated differences between portland cements and this is recognized in specifications for portland cements. But what it measures is essentially not "workability." The device needed must be such that there will be measured the ratio between flow and the pressure causing the flow, especially at different rates of flow. Three such devices have been tried and the results presented before this Institute in 1928.[9] That paper is so recent that it need only be said that each of the methods showed that there was a difference in the workability of the twelve cements used. The authors of the latter have extended

[4]Workability of Concrete: Pearson and Hitchcock. Proc. Amer. Soc. for Testing Materials, Vol. 23, Part II, p. 281 (1923).

[5]A study of some methods of measuring workability of concrete: Smith and Conahey. Proc. Amer. Concrete Inst., Vol. XXIV, p. 24 (1928). Note: This paper is appended with an interesting bibliography covering workability and consistency.

[6]The measurement of workability of concrete: Smith. Proc. Amer. Soc. for Testing Materials, Vol. 28, Part II, p. 505 (1928).

[7]The determination of the workability of concrete: Purrington and Loring. Proc. Amer. Soc. for Testing Materials, Vol. 28, Part II, p. 499 (1928).

[8]For a correct definition of consistency see the discussion by Herschel of a paper by Jackson and Werner, "A new test for consistency of paving concrete;" Proc. Amer. Soc. for Testing Materials, Vol. 25, Part II, p. 204 (1925).

[9]Cement as a factor in workability of concrete: Bates and Dwyer, Proc. Amer. Conc. Inst., Vol. XXIV, p. 43 (1928).

their work to mortars made from different cements, using an apparatus in which is measured the force required to hold stationary a fork projecting into a sample of plastic mortar being revolved at certain constant speeds in a container. This has again shown the marked differences between cements in mortars of different proportionings and percentages of water. It is hoped to enlarge this apparatus and extend its use to a study of the workability of various concretes, making the kind of cement used one of the variables.

It is again evident from this brief review of the studies of this property known as workability that it has been tacitly assumed that the cement was at least a minor variable as compared with the other constituents of concrete. However, it is just as evident that, since cements are now being sold on the basis that they are more "plastic" or will produce more "workable" plastic products than others, it will be necessary to devise apparatus to determine not only whether the cements, as pastes, are as advertised but also whether they produce the quality claimed for them in mortars and concretes.

REACTION WITH NATURAL STONES

It is well known that certain natural stones used in construction contain certain organic compounds, and that these stones in contact with water leached through some cements will develop a brown to almost black stain. Apparently this is not due to any reaction of the organic compounds with lime dissolved from the cement but rather to a reaction with hydrates of sodium and potassium leached from the cements. However, it does not appear that the total amount of sodium or potassium as determined by chemical analysis is a measure of the staining propensities of any cement, but it is rather the rate, especially in early periods after setting the stone, at which compounds of these two elements will be leached out of the cements. Lastly and most emphatically the iron oxide content of the cement is no measure of its likelihood of inducing stain, notwithstanding that the white cements were developed under the erroneous idea that the brown stains on the stone were iron oxide leached out from gray cements and therefore that the white cements containing very small quantities of iron oxide could not produce stains.

The compounds of sodium or potassium in cements are due practically entirely to their presence in the raw materials used in the manufacturing process. Meager amounts may be introduced from the fuels. Hence if it is known that the source of raw materials is low in these elements, it can be reasonably assumed that the finished cement will also be low and consequently the staining propensity low. But since in any case there may be considerable loss of these during burning, due to their volatilization, and since also the amount so lost will depend upon the degree of burning, both as to temperature and to time, it follows that when the raw mixture contains larger amounts it will not be possible to say at any time that the brand may or may not have this undesired quality. It seems desirable, therefore, in all cases to submit the stone and cement *in question* to actual test. This can readily be done by making a cup-like receptacle of the cement in the form of a mortar on the stone, allowing it to set, and then filling with water. As the water leaches through the walls of the receptacle into the stone and out onto the surface of the latter the stain will appear if the organic compound is in the stone and if the cement is giving up the sodium or potassium compounds in harmful amounts and rates. It should be borne in mind that just as cement from the same mill may or may not stain from time to time, so stone from the same general locality may from time to time not contain the organic compounds.

The publications dealing with this subject are few, but reference should be made to the following:

Staining and efflorescence on Indiana limestone caused by moisture seepage through backing masonry materials: Huber. Proc. Amer. Soc. for Testing Materials, Vol. 28, Part II, p. 695 (1928).

Physical properties of the principal commercial limestones used for building construction in the United States: Kessler and Sligh. Bureau of Standards Technologic Paper No. 349.

The staining of Indiana limestone: Anderegg. Purdue Univ. Eng. Review, March 1926.

Non-staining mortars: Bul. 233, Indiana Limestone Quarrymen's Association; also supplementary circular by the same under date of Jan. 3, 1927.

Indiana limestone: efflorescence and staining: Anderegg, Peffer, Judy and Huber. Bul. 33, Eng. Exper. Station, Purdue University.

Certain publications have been issued in which a number of commercial "brands" of cement are arranged in order of their

staining propensities. These are not presented here, since whether a "brand" will or will not stain is influenced not only by the manufacturing conditions cited above but also by the composition of the raw materials used. Since many "brands" are produced at different plants it cannot be said that any "brand" has this undesired quality, but rather only that the product of a mill may or may not be satisfactory at the time it was tested. This fact has not been sufficiently emphasized in most discussions of this question.

SHRINKAGE AND PLASTIC YIELD

It is believed that the information desired under this heading would more likely be referred to as phenomena noted through the volume changes in concrete during the setting and hardening, without regard to any superimposed load. There has been a considerable amount of work devoted to noting the changes in volume (more properly, changes in one dimension only) of various kinds of concrete during the setting and early hardening, as brought about by the chemical reaction of the cement and water incident to the development of strength. One always associates Bauschinger with volume changes as a result of his pioneer studies in this field in 1879. He was apparently interested in the deportment of different cements in this respect, for he used eight different ones in his studies. The other early investigators also used different cements, but confined their studies to neat specimens or mortars. But in more recent years the variables studied have been types of aggregate, proportioning of the mix, amount of water used, temperatures and humidities during storage, etc. It has been assumed either that the cement was of little influence in affecting any volume change or that the amount of cement used in a concrete was, relative to the aggregates, so small that it could have but little effect.

White, one of the earlier and most prolific investigators in this country of the subject of volume changes, in his second paper[10] makes the statement, after mentioning the use of four different portland cements, "A wide variety of types of commercial cements is thus included, but the results are so similar in the case of the portland cements that the curves can all be treated alike."

[10]Volume changes in portland cement and concrete: White. Proc. Amer. Soc. for Testing Materials, Vol. XIV, Part II, p. 204 (1914).

TABLE IV

Per cent changes in lengths of cement specimens

Investigator	Neat Specimen	1:3 Mortar	Remarks
Expansion during storage in water			
Bauschinger[1]	.046	.009	Measurement at 16 weeks
Schumann[2]	.150	.028	Measurement at 1 year
Tomëi[3]	.025	.027	Measurement at 90 days
Considere[4]	.079	.028	Measurement at 63 days
Gary[5]	.063	.008	Measurement at 1 month
Gary[5]	.078	.013	Measurement at 3 months
Gary[5]	.094	.012	Measurement at 1 year
Gary[5]	.092	.020	Measurement at 2 years
Campbell and White[6]	.190		Measurement at 5 years
Contraction during storage in air			
Bauschinger	.214	.132	Measurement at 16 weeks
Schumann		.040	Measurement after 1 week in water and 3 weeks in air
Tomëi	.201	.094	Measurement at 90 days
Considere	.132	.050	Measurement at 63 days
Campbell and White	.390		Measurement at 5 years

[1]Bauschinger: Mitt. Mech. Tech. Lab. d Tech. Hochsch. in Munchen: 8 Heft (1879).
[2]Schumann: Ton. Zeitung. Vol. 5, p. 184 (1881) Vol. 13, p. 435 (1889).
[3]Tomëi: Trans. Amer. Soc. Civil Eng., Vol. 30, p. 16 (1893).
[4]Considere: Compt. Rend. p. 129 and 467 (1899).
[5]Gary: Mitt. Kgl. Tech. Versuchsanstalt zu Berlin: Erganzungheft 1 (1889).
[6]Campbell and White: Jour. Amer. Chem. Soc., Vol. 28, p. 1278 (1906).

His data, presented in graphic form only, do not show any marked differences in the volume change (increase in length, in this work), between the four cements in neat specimens stored in water, until what appears to be 60 days. Then, however, the rate of increase in length appears to be quite different, so that at six months two of the cements had increased in length .075 per cent, the third about .06 per cent, and the fourth .10 per cent. At the end of a year the values are .10, .075 and .15 per cent, respectively. The author apparently intended to indicate in the above quotation only the similarity in trend and not in values in the curves, for it seems that one of the cements in a year had twice the expansion of another. However see White's later paper in the 1928 Proceedings of the American Society for Testing Materials.[10a]

The data presented in Table IV are taken from Table I of an earlier paper of White.[11] The values given are the averages obtained by each investigator, studying from one to ten cements.

[10a]Volume changes of portland cement as affected by chemical composition and ageing: White. Proc. Amer. Soc. for Testing Materials, Vol. 28, Part II, p. 398 (1928).
[11]Destruction of cement mortars and concrete through expansion and contraction: White Proc. Amer. Soc. for Testing Materials, Vol. XI, Part II, p. 531 (1911).

For the actual range in values obtained by each investigator reference must be made to the original paper but, even without the latter, it can be seen that there is a marked difference in cements in respect to their volume changing during hardening. The data are for cements made many years ago and cements have surely changed in certain respects since then, but it is hardly likely that they would show less differences in the quality under consideration now than then. How much such differences would affect concretes is rather difficult to surmise, since cement has seldom been made a variable in the study of volume changes in concrete.

Hatt, however, has drawn some relations between the volume changes of neat cements and those of concretes made therefrom in two of his publications.[12,13] He states in his "Researches in Concrete," that "neat cement which contracted in air during 90 days, subsequent to immersion, to the amount of .142 per cent, when made into a 1:2:3.5 gravel concrete shrank .035 per cent after 90 days. Another cement which showed a contraction 90 days subsequent to immersion of .073 per cent, when made into 1:1.5:3 gravel concrete shrank .015 per cent after 90 days in air." The reader is referred to Hatt's "Researches in Concrete" for an excellent digest and bibliography of "Expansion and Contraction" of cement and concrete. Fig. 1 is reproduced from Hatt's "Physical and Mechanical Properties of Portland Cements and Concretes" (Bul. 24, Eng. Exper. Station, Purdue Univ.), and is illustrative of how cements may differ in their coefficients of dilation during hardening.

There is a rather voluminous literature on this subject wherein the cement has not been a variable and those particularly interested should closely study certain of the publications, such as those of Pearson,[14] Hatt,[15] and Graf.[16] These are of special interest in showing that marked changes are taking place during setting and that unless measurements are made while the early hardening is taking place, at which period the concrete is still plastic, rather erroneous ideas of the total movement will be

[12]Effect of moisture on concrete: Hatt. Proc. Amer. Soc. Civil Engineers, May 1925.
[13]Researches in Concrete: Hatt. Bul. 24, Eng. Exper. Station, Purdue Univ.
[14]Shrinkage of portland cement mortars: Pearson. Proc. Amer. Conc. Inst., Vol. XVII, p. 135 (1921).
[15]Extensibility of concrete: Hatt. Proc. Amer. Conc. Inst., Vol. XXII, p. 364 (1926).
[16]Volume change of cement and cement mortars during setting: Graf. *Beton und Eisen*, 1921-22.

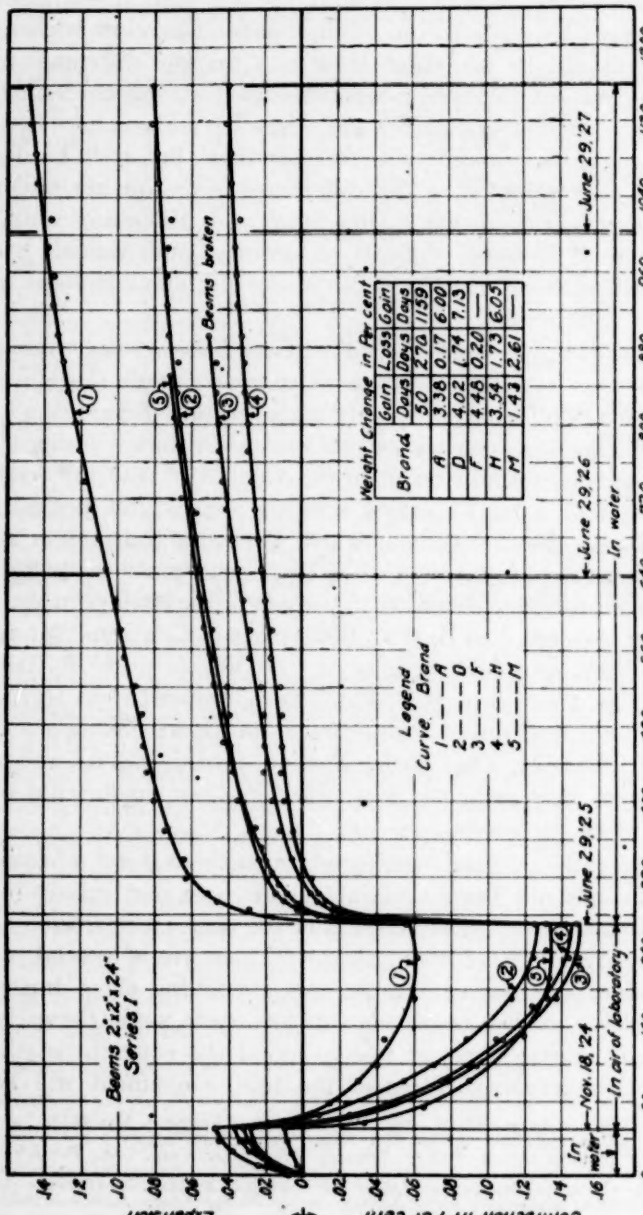

FIG. 1—EXPANSION AND CONTRACTION OF NEAT CEMENT BEAMS (FROM HATT'S "PHYSICAL PROPERTIES OF PORTLAND CEMENTS AND CONCRETES").

obtained. This is cited here because too many investigators have not started measurements until after the first 24 hours or more, when the cement product has secured considerable of its strength, attained and passed a considerable amount of its total volume change, and possibly acquired in so doing some internal strain.

The question of plastic yield of set concrete under load has not to our knowledge been studied from the viewpoint of how it may be affected by the use of different cements. Those interested in the general subject, without particular regard to the brand of cement used, may find a bibliography in Hatt's publications cited in footnotes 12 and 13, and also in the report of Sub-Committee XVI of Committee C-9, contained in Proc. Amer. Soc. for Testing Materials, Vol. 28, Part I, pp. 376-393 (1928).

CHEMICAL HEAT OF SETTING IN LARGE MASSES

The heat generated during setting of concrete has attracted the attention of many for a considerable period of years. Further, those who have studied the question have properly connected it with shrinkage, since initially if the concrete has reached a temperature during setting above that of the surrounding atmosphere contraction must result during later cooling, unless the concrete is of the rather unusual yet possible kind that would expand during hardening.

A very extended discussion of this subject appears as a result of the paper by Gowen[17] in the Transactions of the American Society of Civil Engineers in 1908. Merriman in discussing the paper makes a statement which should be clearly borne in mind on account of its significance regarding the magnitude of the temperature change and because of coupling it with induced tensile stress. He states "that in any masonry dam the maximum range in temperature which causes tensile stresses in the masonry is the difference between the temperature at which the cement assumes set and the cement temperature which may subsequently be reached." This brief statement clearly indicates the importance of the heat evolved during setting. Since the maximum temperature which may be reached after hard set has taken place may be 50° F. higher than the surrounding normal temperature, and since further in many cases the atmospheric temperature

[17]The Effect of Temperature Changes on Masonry: Gowen. Trans. Amer. Soc. Civil Engineers, Vol. LXI, p. 399 (1908).

range may be 100°, it follows that volume changes (shrinkage) may be induced by a temperature drop of 100 to 150° F.

Those who are interested in the full import of this matter should consult the December, 1928, issue of *Hydraulic Engineering*. The papers in this issue, "Gravity Dams Subject to Internal Stresses which Result in Undesirable Fractures," by Noetzli, "Temperature Variations in Concrete Dams as a Probable Cause of Unusual Stresses," by Floris, and "Distribution of Major Stresses in Arch Dams Should Be Uniform Throughout the Structure," by Vogt, all deal more or less with the question of heat evolution during setting and the resulting shrinkage during cooling of dams. Many very valuable references to this subject will also be found here.

Although the shrinkage of large masses of concrete due to cooling following the heat of setting has a proper place in this present paper only insofar as it concerns different cements, yet the liberty is taken of presenting here certain data and comments from these three papers in the above cited issue of *Hydraulic Engineering*. Floris gives the following data regarding the temperatures developed in certain dams. (He also gives the reference from which he obtained the data.)

Name of Dam	Maximum Temperature Reached	Period of Measurement
Kinsico	118°F	3 years
Wilson	113°F	8–9 months
La Jonge	104°F	1 year
Arrowrock	96°F	3 years
Spaulding	91°F	4 months
Boonton	78°F	3 years
Waldeck	64°F	over 1 year
Rock Creek	62°F	17 days
Stevenson Creek	117°F	4.5 months

Although undoubtedly different cements were used in these structures, there were so many other variables (size of structure, amount of concrete placed daily, proportions of aggregate used, etc.,) that it would be rash to assume that the differences in temperature developed were due to the use of different cements. Floris makes the following statement: "At the highest temperature of the concrete, the dam is free of stresses as mentioned previously. As soon as the temperatures drop, however, stresses

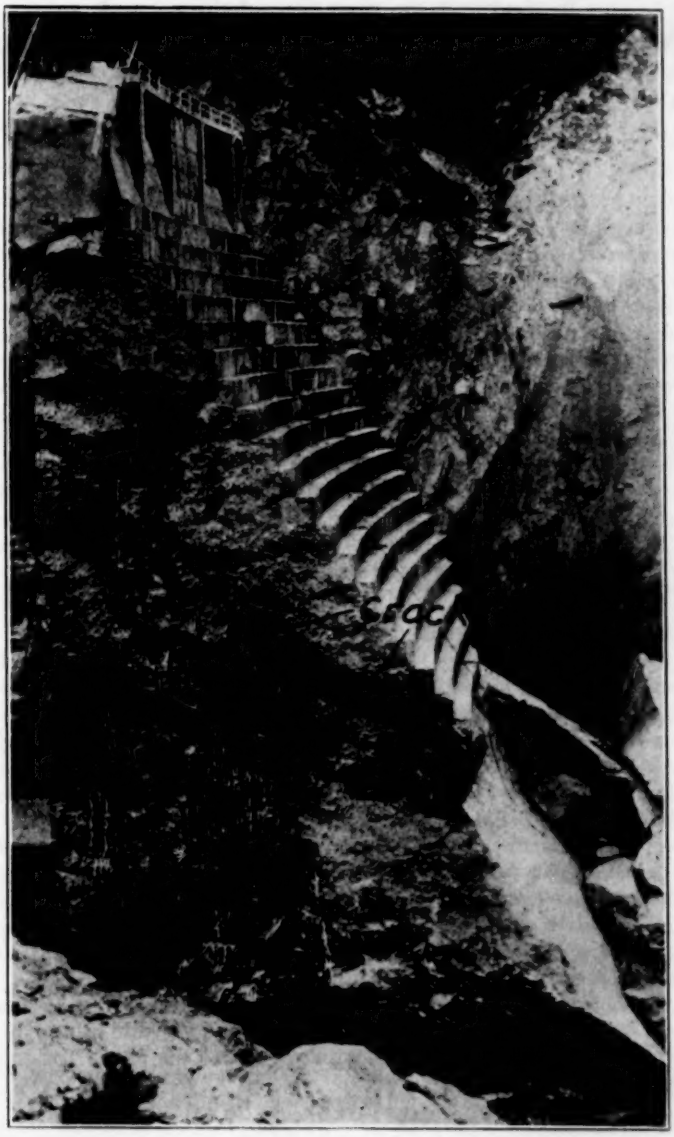

FIG. 2—CRACKS IN A PORTION OF ST. FRANCIS' DAM (FROM NOETZLI IN "HYDRAULIC ENGINEERING").

are developed and the concrete begins to shrink slowly. According to Dr. W. Ludten[18] the shrinkage of the concrete takes place 700 times slower than the falling off of the interior temperatures due to the chemical effect."

Fig. 2, reproduced from Noetzli's article in the issue of *Hydraulic Engineering* above referred to, shows very clearly the shrinkage cracks in the large portion of the St. Francis Dam remaining standing. Commenting upon this Noetzli says:

As stated by Lars Jorgensen,[19] the contraction joints in the Lake Spaulding Dam were placed 80 feet apart and shrinkage cracks developed during the first winter after completion of the dam midway between each two joints. Similarly in the St. Francis Dam in which no contraction joints were provided, vertical cracks from 50 to 75 feet apart developed in approximately radial planes. The breaking up of the structure at the time of failure into a number of vertical slices, of which the remaining middle prism is a vivid illustration, is a striking instance of the desirability of concrete dams being provided with contraction joints.

While ample proof of the shrinkage of the concrete of dams in a longitudinal direction has long been available, the failure of the St. Francis Dam, exposing the interior of the structure, has furnished startling evidence of similar shrinkage in an upstream and downstream direction, resulting in the formation of inclined cracks in the interior of the dam.

To take care of this shrinkage Noetzli then suggests the procedure indicated in Fig. 3. In suggesting this he states:

At present the shrinkage of the concrete of gravity dams appears to be unavoidable. Vertical contraction joints have largely eliminated undesirable effects of shrinkage in a longitudinal direction. In some recent designs it is proposed to take care of the shrinkage in a transverse direction by providing inclined contraction joints in the interior of such dams. A notable example is the San Gabriel Dam, a structure of the gravity type of about 500 feet in height. . . . It will be provided with three internal contraction joints arranged after careful computation in planes parallel to the principal stresses for the dam under full load. In these planes the strain is zero. There is therefore no tendency of a relative movement taking place of the concrete surfaces on either side of a joint. On the other hand the joints may open or close according to the tendency of the concrete to shrink or expand due to shrinkage or a change of moisture or temperature of the concrete.

Such included joints have been used with gratifying results in the buttresses of the Coolidge Multiple Arch Dam in Arizona, and they are being provided in the buttresses of the Big Dalton Multiple Arch Dam of the Los Angeles County Flood Control District.

Vogt, in his article referred to above, says:

[18]Temperaturveranderungen in Beton infolge der abbindenwaerme und unter dem einfluss der umgebungs-temperatur und der sonnenbestrahlung: Ludten. Der Bauingenieur 1924: Nos. 23, 24.

[19]Trans. Amer. Soc. Civil Engineers, Vol. 78, p. 716 (1915).

It has been claimed that swelling of concrete due to water soaking would produce ideal conditions and justify the use of the cylinder formula. It is general experience that contraction joints open up, not only at the surface of the concrete dam, but also in the interior of the majority of both thin and thick dams, as can be seen in the inspection galleries. Furthermore, the experience is that after some years these joints are enough open to make a

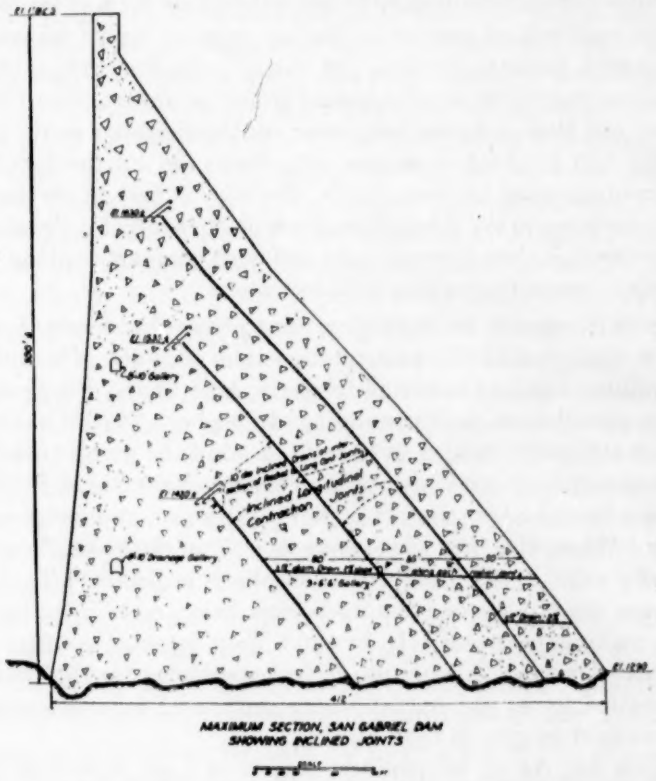

FIG. 3—CONTRACTION JOINTS IN SAN GABRIEL DAM (FROM NOETZLI IN "HYDRAULIC ENGINEERING").

grouting possible, which proves the cooling from the high setting temperatures in the long run more than offsets the swelling due to water soaking. Dams which are not provided with contraction joints usually crack, which is a further indication of the same thing. . . . In thick dams both the moisture content and the temperature in the interior will change very slowly and the opening of the joints can hardly be explained by seasonal changes in the temperature or by drying out of the concrete due to emptying of the reservoir.

The tests, for instance, from Arrowrock Dam[20]; show that by forming the concrete in layers of a reasonable thickness and with a reasonable progress in the work, a rather high initial temperature will be developed due to setting of the concrete, and that this chemical heat disappears very slowly in thick dams. With thicknesses of 100 to 150 feet about one-half of the initial temperature will remain after from four to nine years, respectively, and the chemical heat will not disappear entirely before two or three times this time has elapsed.

The author then goes on to discuss grouting under pressure in contraction joints to produce "an upstream load on the cantilever counteracting the downstream load from the water pressure" and points out that if done early, later contraction due to the later cooling will produce shrinkage not eliminated by the grouting. As grouting must be done before the dam is first in service, he calls attention to the possibility of artificial cooling by circulating water through slots formed in the different compartments in construction joints spaced about 50 feet apart.

There is possibly no more important phase of concrete investigation neglected at the present time than this one of shrinkage (or volume change) resulting from the heat of the chemical reaction plus that of the surrounding atmosphere. What has been done is strikingly lacking in bearing in mind the many variables. Thus generally in making volume change observations, recourse has not been had to control of temperature or humidity conditions. When this has been done the conditions which might actually exist in practical work have been neglected. Take for instance the studies of volume changes in concrete intended for road making purposes. It has not been possible to find any records where any one permitted test specimens for the purpose in question to set and harden under such conditions of temperature as exist largely in road making.

When control of temperature has been had, it consisted of maintaining the specimens at all times at an "average" or "normal" temperature of about 70° F. But in road making, carried on as it is largely during the summer months, the temperature of the materials and the atmosphere may reach 100° and more before the reaction of the cement and water starts. By the time the reaction has proceeded until rigidity of the mass is obtained, the temperature may be 10 to 30° higher. Then in from 6 to 9 months, during the winter, the temperature of the

[20]Trans. Amer. Soc. Civil Engineers, p. 1225 (1915).

mass will have fallen to possibly below zero. Hence it is not surprising that laboratory results, obtained under such totally different conditions from those existing in the field, do not indicate the cracking of concrete whereas the cracking may actually take place in the field.

There have been some data published from time to time bearing more properly on the subject at hand—the different heats of reaction with water of different cements. The 1901 report of the Waterton Arsenal gives the temperature rise at the center of 12″ cubes of neat cement made of 13 different cements (natural and portland). Thermometers inserted at the center were used to indicate the temperature. The specimens in board forms and with top exposed to the air were maintained in the air during hardening. The maximum temperature noted was 103.5° C. and the minimum 42.5° C. (for a portland cement). The natural cements developed much lower temperatures. Gary[21] in his work used several different cements but was more interested in the development of certain equipment and the relation between the determination of the time of set by needles and by measurement of the evolution of heat. Cushman discussed the matter before the 8th International Congress of Applied Chemistry in 1912 and Beals presented a paper in 1913 before the American Society for Testing Materials on "Thermal Activities of Portland Cement During the Period of Setting" (p. 720, Vol. XIII).

The data presented in Table V through the courtesy of Mr. Thaddeus Merriman from unpublished data obtained by him, and that in Fig. 4 from data obtained at the Bureau of Standards, are believed to be as complete and illustrative as any available.

Merriman obtained his data by mixing 450 grams of cement with 112 ml of water in a tinned can, three inches in diameter and three inches high. This was placed inside of a specially constructed calorimeter and the temperature of the mixture determined by the use of thermometers read at 15 minute intervals. The heat losses of the calorimeter were also determined at different temperatures and the temperatures read on the thermometer corrected according to the previously determined heat losses.

[21]Uber neue Abbindeversuche mit Portlandzement: Gary. Protokoll Vereins deutsche Portland Zement Fabrikanten 1905, p. 155.

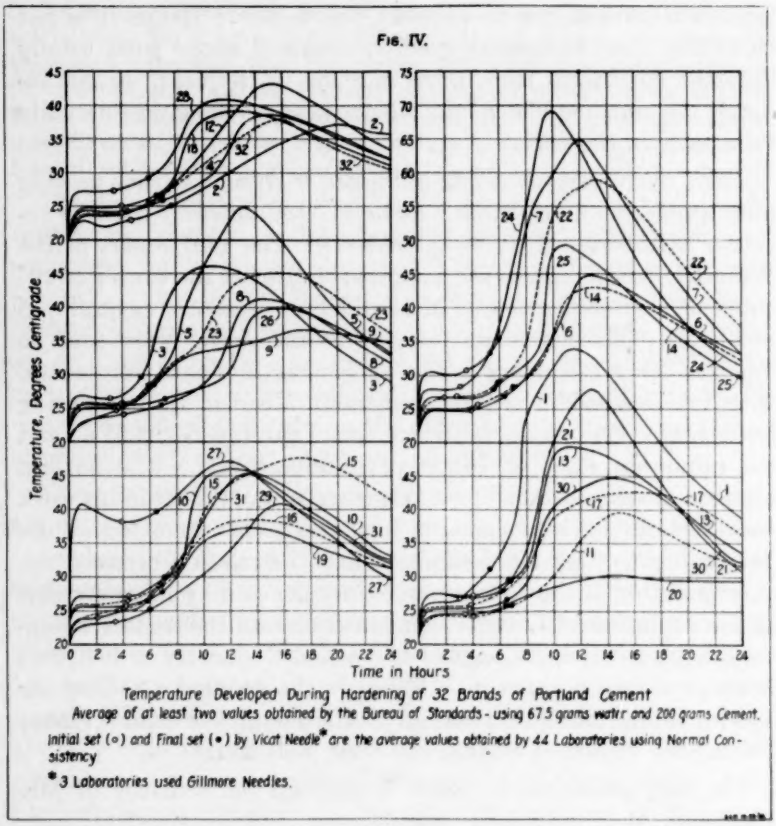
FIG. IV.
Temperature, Degrees Centigrade
Time in Hours
Temperature Developed During Hardening of 32 Brands of Portland Cement
Average of at least two values obtained by the Bureau of Standards - using 67.5 grams water and 200 grams Cement.
Initial set (○) and Final set (●) by Vicat Needle* are the average values obtained by 44 Laboratories using Normal Consistency
*3 Laboratories used Gillmore Needles.

FIG. 4.

At the Bureau of Standards 200 grams of cement were mixed with 67.5 grams of water by a high speed motor-driven stirrer for one minute, in a tinned can 2⅜ inches in diameter and 3 inches high. This was then placed in a thermos jar, closed and placed in a cabinet maintained at 70° F. ± 2° for 24 hours. The temperature was read by multiple junction base metal thermocouples and recorded by a sensitive potentiometer.

The same cements were used by both Merriman and the Bureau of Standards. They are described and their properties given in the report of Committee C-1 of the American Society for Testing Materials to that Society at its 1928 meeting (Proc.

A. S. T. M. 1928, Part I, p. 233). The numbers used in Fig. 4 and Table V to differentiate the cements are the same as those used in the committee report.

TABLE V

Total Temperature Rise (Degrees F.) of Neat Pastes of Thirty-Two Brands of Cement

(Data supplied by Merriman, Chief Engineer, New York Board of Water Supply.)

450 Grams Cement: 112 Grams Water

Cement No.	Rise at 8 Hrs.	Rise at 16 Hrs.	Rise at 24 Hrs.
1	151	196	198
2	38	124	140
3	141	158	158
4	36	138	149
5	119	170	171
6	105	176	184
7	153	171	174
8	98	172	174
9	105	159	159
10	63	138	147
11	84	172	180
12	93	135	151
13	131	180	187
14	85	156	176
15	47	169	171
16	85	171	179
17	90	182	185
18	72	160	172
19	45	142	154
20	40	100	118
21	129	174	177
22	146	205	208
23	95	159	162
24	146	153	153
25	93	141	149
26	33	147	166
27	132	155	156
28	83	121	127
29	96	162	171
30	96	159	159
31	100	142	151
32	65	129	138

In Fig. 4 there is also indicated the time of set. This shows that final set (assuming some rigidity) has taken place before the maximum temperature has been obtained. Both laboratories obtained data which show that there is a marked difference between brands in respect to the property under consideration.

But just how much difference there would be in the deportment of concretes made from these cements can be but a matter of

conjecture. It would be reasonable to assume that the concrete would develop about the same relative variation, but it would be most interesting to know definitely whether this would be the case or if on the other hand those cements which as neat pastes developed high temperatures might not in large masses of concrete develop relatively higher temperatures than the other cements. Such data as these presented merely indicate the need of further study, particularly of concrete so hardened as to acquire temperatures more in accord with those obtained in mass concrete in actual jobs than the usual procedure generally permits.

REACTIONS TO CURING CONDITIONS

The failure of obtaining results of strength determinations that could be reproduced from day to day has long since convinced all interested in the need of controlling particularly the humidity, and to a less degree the temperature of the atmosphere in which cement and concrete specimens are cured. But just how much either of these two necessities would affect different cements has not been a matter of much investigational concern. The committee therefore cannot cite many data that would show if curing conditions would indicate differences in cements.

In general laboratory procedure, specimens having portland cement as a binder are invariably stored in water or in an atmosphere about saturated with water vapor. Such conditions are fairly readily obtained, but in many localities it is difficult to maintain the temperature throughout the various seasons without an expenditure of money that in many cases seems unjustified. Hence in the great majority of cases no attention is paid towards maintaining a fixed adopted temperature or trying to evaluate properly what has been the effect of a variation from the usual normal temperature of the atmosphere. There have been investigations studying the effect on strength of concrete cured at freezing or slightly higher temperatures, and at temperatures around that of boiling water or somewhat higher, through the use of autoclaves. But when the data are examined it will invariably be found that the cement has not been a variable. Thus, Bulletin 15 of the Structural Materials Research Laboratory of the Portland Cement Association at Lewis Institute, gives data

covering five methods of curing concrete, in moist air by covering with damp earth, air curing, covering with asphalt impregnated paper, sprinkling with flake calcium chloride, and painting with a 41° Baume solution of water glass. But it states, "portland cement (A) purchased from dealer's warehouse at Sacramento was used."

A report of the work done annually by the laboratory of the German Portland Cement Manufacturers Association will be found in their annual proceedings. This always gives the results obtained in testing the products of the association members according to the German standards. Since, further, two methods of storage are specified for the mortar specimens to be tested at 28 days, some idea of the deportment of German cements in this respect as mortars can be obtained by reference to these publications. One of the storage or curing conditions consists in placing the specimens, after removal from the molds at the end of 24 hours, in water until tested; the other requires the same procedure for the first 7 days and then storage in the air of the laboratory. The specimens cured according to the last procedure invariably give higher strengths, notwithstanding the idea so prevalent in this country that dry specimens will give lower strengths than wet ones. The controlling feature in this latter matter is not so much whether the specimen is dry or wet when tested as what is the age and throughout what length of time during its age has it been wet or dry.

Somewhat similar data for mortars made of ten domestic cements are given in a paper in the 1923 Proceedings of the American Society for Testing Materials.[22] The strengths both in tension and compression of 1:3 standard sand mortars are higher when stored for approximately the first quarter of their life in water and the remaining three-quarters in air than when stored for similar periods continuously in water. This holds at the end of five years, which was the last age at which specimens were tested. The effect of the two kinds of storage is different for the several cements, but there does not seem to be any apparent explanation of why this should be. As the cements used were

[22]Late Data on the Effect of Finer Grinding and a Higher SO_3 Content upon the Physical Properties of Portland Cement; Bates. Proc. Amer. Soc. for Testing Materials, Vol. 23, p. 248 (1923).

bought on the open market it was not possible to have much data on the nature of their constitution, or the degree of "aging" during warehousing, which are essential for the possible explanation of differences in the hardening of cements.

Table VI.

1:2:4 limestone concrete made from 15 cements, stored for ages shown in the damp closet (D. C.) or in the air (A) on a roof.

Age	Storage	Cement Numbers														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
28 d.	D. C.	3050	2730	2520	2550	2410	2640	2700	2280	2220	2200	2300	1770	1780	1810	1990
	A	2870	2780	2820	2680	2430	2820	2730	1940	2110	2240	2190	1870	1870	1820	1990
6 mo.	D. C.	4120	3500	3680	3710	3770	3500	3680	3710	3770	3710	4080	3600	3710	3460	3350
	A	3620	3700	3460	3090	3160	3690	3460	3090	3160	3100	3160	3060	3250	3100	3150
1 yr.	D. C.	4630	4510	3810	3790	4200	4680	4250	4210	4380	4620	4960	4580	4490	4580	4470
	A	3400	2970	2870	2780	3090	3330	3340	3150	3320	3290	3380	2800	3340	3000	3040
5 yr.	D. C.	5010	4110	3870	4270	4050	4550	4490	4450	4750	4580	4810	5020	5110	4990	4910
	A	4140	3950	3960	3600	3660	4240	4100	3950	4200	3700	4250	4580	4190	4280	4230

Table VI presents certain data obtained at a cement plant where a number of cements of different composition were obtained. All of these met the requirements of the American Society for Testing Materials. In the table only the strengths of 1:2:4 limestone concretes at the ages of 28 days, six months, one year, and five years are given. One set of three 6 by 12 cylinders was stored in the damp closet after 24 hours in the molds, and one set on the roof after the first 24 hours in the molds followed by six days in the damp closet. It will be noted that at 28 days there was not much difference in the strengths as a result of the different storages. With some of the cements one storage gave the higher strengths and with others the opposite was noted. At six months the lack of water for further hydration needed for gain in strength by the roof-stored specimens is indicated by the almost general higher strengths and good gain in strengths of the damp closet-stored specimens, compared with the low strengths and lack of gain of the roof-stored specimens. This is very decidedly indicated by the one year specimens. At this age the concrete made from all the cements tested much higher after storage in the damp closet than after storage on the roof. Note also that the roof-stored specimens in the majority of cases showed less strength at one year than at six months. This is evidence not only of lack of hydration but also of drying out to the extent that the bond formed by the cement already reacted upon is losing strength.

The six months period between the testing at ages of six months and one year also came at a season of the year of very little precipitation and very low atmospheric humidity.

At five years, however, the two storages are indicating more similar strengths for any cement, the damp closet-stored specimens showing less gain than the air-stored specimens. During the period between the one and five year tests precipitation had caused hydration at a greater rate in the roof-stored specimens than in the damp closet-stored specimens, already more completely hydrated at the end of one year.

The study of methods of curing and the effectiveness of the methods in reducing cracking and increasing strength and durability should be far more actively pursued than it is. It is a matter of considerable interest to note that this is being done under the auspices of the National Research Council, insofar as road building is concerned. But the matter should be of just as much concern to all the other construction groups using cements.

COLOR

Of the many properties of portland cement which may be reflected in concrete none is of as little interest or concern as that of color. Further, none of the properties is considered to be more uniform than that of color. But it is nevertheless true that cements and concretes do differ in color. However, generally this is so slight that unless specimens are in close proximity to one another one cannot appreciate any difference in the tints. It should be borne in mind that white portland cement is not being considered here, although when it is used with darker colored sands and aggregates it is surprising how difficult it is to differentiate it from gray portland cement used with the same aggregates.

Portland cement is generally referred to as being gray in color. This is essentially true, although certain cements are at times of a distinctly yellowish tint and might be said to have a tan color; others have enough of a red tinge to partake of a muddy brown color. In any case these colors are due to two or three of the minor oxides present in the raw materials: titanium oxide to a lesser degree and iron and manganese oxides to a greater extent. The pure compounds of lime, silica and alumina, which comprise 90 per cent or more of cement, are white. Although all three of

the first mentioned oxides are seldom present in total amounts of more than five per cent they produce the color in the cement. This color, however, is modified by the oxidizing or reducing atmosphere of the kilns, the temperature during burning, and certain unknown conditions during cooling. Generally the higher the iron oxide content and the more reducing the flame the darker gray the color. Low burning with high iron oxide content gives the tan shades and with low iron oxide the light gray shades. The muddy brown cement is the result of the presence of manganese which in some cements may approach a maximum of one per cent when calculated as the dioxide.

It requires rather a color sensitive eye to note the differences in color produced in concrete by the use of widely different colored cements (other than white cement). This is particularly true of the tan or gray cements; the brown cements are inclined to yield a concrete rather readily distinguished by its more brownish shade. But in few cases is the difference in color sufficient to be objectionable. Rather, the slight differences are pleasing in breaking up the monotone.

There is, however, one feature regarding the color or tint of concrete which should be always seriously considered. This refers to the color, lacking "life," whatever that may be. A dead chalky-appearing concrete is an excellent indication of poor concrete and furthermore, more particularly, of poorly made concrete. While it is almost impossible to define a "live color" or tint, there is no mistaking such a one when compared with a dead one, and the bringing together of a piece of well-made concrete of almost vitreous texture and a piece of concrete made from an over-watered mix, with its chalky powdering texture, will leave no doubt in any ones mind as to the significance of the term. Once having noted this condition it is one that should be borne in mind. The appearance of a chalky, too sandy fracture, in the matrix in concrete, coupled with a lack of life in its color, be that what it may, is quite positive evidence that too much water has been used in the mix. The appearance of the matrix under such conditions is very similar to that of laitance, and the resemblance extends beyond this physical appearance to the actual conditions under which they were produced—namely—the use of too much water.

CONCLUSION

This paper has been developed along the general lines suggested to the committee. It is at some fault in not showing in all cases that different brands of standard portland cement have different physical properties or react differently under various conditions of service. But this fault is due to the lack of data in some cases which would support such a thought. This lack of data in turn is due to the assumption that all brands will at all times be similar in every respect. Hence, in investigative work in which cement might have properly been considered a variable, it was assumed to be a constant. In this paper an effort has therefore been made to show that it would have been just as logical to have assumed that various cements might at any time have different physical properties. The various properties of concretes have as a consequence been considered in the light of the fact that these properties may be materially affected by the character of the cement. The urgency of studying all the properties of concrete as resulting in a major degree from the quality of the cement is stressed. There can be no constituent of concrete more worthy of study than the cement—without it there is no portland cement concrete—yet as an essential constituent of concrete it has been studied less than any of the other components.

DISCUSSION

BY THADDEUS MERRIMAN

MR. BATES, as Author-Chairman of Committee 202, has performed a significant service in the cause of portland cement. His paper points out with singular clearness the vital fact that no two cements are alike in all of their characteristics and, as an inescapable corollary, he shows that cement must be considered as a variable if the results of tests on concrete and mortar are to be intelligently evaluated.

For many years the writer has earnestly sought to present this same aspect of the problem and he therefore heartily concurs with the presentation of the author. Yet he would go further and suggest that a partial remedy for the present uncertain situation as to cement quality is to be found in a specification for portland cement which will relate the strength it develops to its content of

lime. An overlimed and underburned cement will show a strength sufficient to pass the ordinary specification. It will make a plastic concrete but, under outdoor exposure, will tend to disintegrate. The plasticity comes from the laitance which is produced by the rapid hydration of the underburned cement particles even before the concrete leaves the mixer. Nobody wants laitance because everybody knows it to be undesirable. Yet many cements now in the market develop laitance in large proportion.

The present specification for cement may be likened to a specification for structural steel which contains no requirement for elongation. Such a specification would be just as one-sided as is the so-called standard for portland cement which, predicated on strength alone, contains no requirement for "completeness of manufacture." But progress in this direction is in sight. The kind of cement needed for use under outdoor and hydraulic exposures is being made and can be had if only the consumer will write his specification accordingly. Recent contracts prepared under the direction of the writer, and calling for 1,500,000 barrels of cement, specify that the tensile strength of mortar briquettes shall not be less than 275 pounds at 7 days and not less than 375 pounds at 28 days. It is also required that the molecular ratio first suggested by Colony[1] shall not exceed 2.60. The alumina is held below 7 per cent., the magnesia below 4 per cent. and the sulphuric anhydride below 1.75 per cent. The cement furnished under this specification is of excellent quality. Laitance appears not at all; the compressive strengths are high and the *texture* of the concrete begets confidence because of its firm and rocklike appearance. It is an excellent cement but can be made still better by holding the molecular ratio down to say 2.45.

The time is close at hand when we must put aside the conceptions of cement compounds which have been our guide for some years past. These concepts may ultimately be developed and become of value, but for the present they are not even useful as symbols for pointing the way to progress. Tri-calcium silicate and di-calcium silicate have been the passwords in a large part of the literature on portland cement, yet the existence of these compounds in the cement of commerce has never been conclusively

[1] "Judging the Quality of Portland Cement." Trans., Amer. Inst. Mining and Metallurgical Engineers, 1921.

demonstrated. Theoretically it would be of value to know the compounds which are present but practically it makes little difference. We may just as well, for the purpose of discussing the problem, assume that all cement contains four types of compounds and describe each by the characteristics it develops in concrete rather than by its chemical formula. Thus, the existence of the following compounds may be predicated:

Type A—Makes durable and resistant concrete of high strength. Its constituents are closely and intimately combined.

Type B—Makes strong concrete but develops laitance and tends to disintegrate. Its constituents are indifferently combined.

Type C—Makes concrete of fair strength which disintegrates easily. Its constituents are loosely combined and it develops much laitance.

Type D—Develops no strength in concrete and readily disintegrates. Its constituents are only barely combined and it acts merely as an adulterant which makes much laitance.

Each of these types may be further divided but the four enumerated serve to illustrate the principle that all portland cement is a mixture of a number of types of compounds. The proportions of the several types vary in different cements from different mills and often from hour to hour in the same mill. One cement consisting largely of Types A and B is an excellent product. Another contains a little of each of Types A and D and much of Types B and C. It is a medium cement which tends to disintegrate on exposure. A third cement may consist of Types B, C and D, with C predominating; it will show good strength but will quickly disintegrate and will show much laitance. All of these three assumed combinations will pass the usual specification requirements. They sell at the same price yet they are not of equal value in the concrete they produce. The great need of the engineer is for a test which will enable him to select that cement which is best suited to his work. Such a test, however, will not come to be recognized until both producer and consumer understand that portland cement as produced in the rotary kiln is not a fixed and definite compound, but is, in fact, subject to many variations which, oftimes, are of great magnitude and are not disclosed by a specification which merely calls for a minimum strength. Under such a specification low grade products are hallmarked as equal to the best. In no other field of material used in engineering structures does such a condition obtain.

The author has indicated numerous points on which cements differ and it may be of interest to present still another as to the group of 32 cements to which he has referred. Using the method of sugar solutions described by the writer,[2] the results in the following table were obtained on these cements. The designating numbers being the same as those used by the author and by Committee C-1 of the A. S. T. M.

Cement No.	Solubility of 10 Grams in 100 cc of 15% Sugar Solution	*Solubility of 7½ Grams in 100 cc of 15% Sugar-Lime Solution
1	40.9	42.3
2	4.4	11.7
3	35.5	38.2
4	3.9	25.4
5	39.1	33.9
6	44.7	36.1
7	20.4	31.2
8	32.8	31.9
9	11.8	28.1
10	24.0	29.6
11	4.6	27.3
12	6.1	24.8
13	21.2	35.7
14	6.4	31.6
15	21.3	33.8
16	35.4	38.8
17	40.1	40.5
18	29.8	32.4
19	27.4	31.5
20	7.5	19.7
21	34.5	36.3
22	41.3	39.4
23	4.9	26.2
24	5.2	34.0
25	16.4	30.3
26	2.2	20.5
27	36.6	38.3
28	8.2	25.6
29	5.0	29.2
30	27.0	30.1
31	18.3	24.3
32	12.8	25.9

The solubilities reported in the above table are those indicated by the end point of the methyl orange used in the titrations.

*To the sugar solution used in this test sufficient calcium hydrate was added to require 5 cc of the N/2 acid for neutralization. With this sugar-lime solution the 7½ grams of the cement were then agitated as in the case of column 2. The solubilities reported include the acid necessary to neutralize the initial alkalinity.

[2] "New Studies in the Properties of Portland Cement."—Engineering News Record, Oct. 23, 1924.

If the constituents of these cements had been alike in composition and constitution, the solubilities in the above table should, for each test, have had the same value for all the cements. The compositions of the cements as indicated by the chemical analyses were, generally, similar, and so it may reasonably be inferred that they were in fact very widely different as to their constitutions.

In the above table it is interesting to note that the addition of lime to the sugar solution actually increased the solubilities of the cements. The action of the lime thus seems to be analogous to that of a key unlocking a door. Apparently the constituents of the cement are broken down in the sugar solution by the very presence of the lime itself. This is a circumstance of much import and is being further developed.

The author discusses the effects of shrinkage of concrete in masonry dams and presents a photograph, Fig. 2, of the St. Francis Dam, on which certain cracks have been indicated. It should be noted in this connection that any crack which may have shown on this surface of the dam can hardly be held as indicative of any condition within the mass of that structure. Certainly no cracks of this kind appeared on the opposite and corresponding face of the standing section of this dam. The face on which the cracks are indicated is the face of a shrinkage crack which existed before the failure. On such a face local and irregular crackings in almost every direction are to be expected. Conclusions from evidence of this nature must be drawn with care.

The author also presents a cross section of the San Gabriel Dam. This section shows inclined expansion joints in planes parallel to the axis of the structure. A quotation presented by the author indicates that these joints are in planes parallel to the principal stresses for the dam under full load; that in these planes the strain is zero and that there is therefore no tendency to relative movement of the surfaces on either side of the joint. The assumption that the principal stresses will be parallel to the joints when the dam is under full load should be viewed with the closest scrutiny. Unless it be precisely realized, stresses must be carried both across the joints as well as along them. This assumption, moreover, cannot apply either while the reservoir is empty or while it is filling. The deflection of a liminated beam is necessarily

greater than that of a solid one. So far as present knowledge of shrinkage cracks in masonry dams is concerned, it would seem to be reasonably sound to permit such cracks to occur as they may, in the knowledge that they will naturally interlock and thus provide for the transfer of at least some stress without introducing possibilities which are not susceptible of exact evaluation. The effects of longitudinal cracking, if any, may be almost entirely eliminated by providing a drainage system close to the upstream face, so as to prevent the penetration of water into the body of the dam.

Great credit is due the Author-Chairman for the manner in which he has presented the subject before his Committee. In the judgment of the writer, his paper marks the beginning of a new era in portland cement for both manufacturer and consumer.

Readers are referred to the JOURNAL *for March, 1930, for further discussion which may develop.*